GenRad

GR1633-A Incremental Inductance Bridge

Form 1633-0100-00

Instruction Manual

READ COMPLETE INSTRUCTIONS BEFORE OPERATING BRIDGE

WARNING

The outputs of the ac and dc generators must be reduced to zero before connections are made to the UNKNOWN or to the GENERATOR terminals, and before the setting of the RANGE SELECTOR switch is changed. The leads to the unknown should always be connected and disconnected at the bridge terminals, not at the load.

GR 1633-A Incremental Inductance Bridge

and

GR 1630-AV Inductance Measuring Assembly

Form 1633-0100-00

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Concord, Massachusetts, U.S.A. 01742
December, 1988

Specifications

Ranges and Accuracy:

Measurement	Frequency	Full-Scale Ranges a	b	c	d	e	f	Lowest Scale Division	Accuracy
Inductance	50, 60, 100, 120 Hz	10 mH	100 mH	1 H	10 H	100 H	1000 H	20 μH	±(1% of reading or 0.1% of full scale) ±(2π f_{kHz}/100 Q_x) %*, ±2% above 10 kHz or ±3% above 15.75 kHz
	400, 800, 1000 Hz	1 mH	10 mH	100 mH	1 H	10 H	100 H	2 μH	
	10, 15.75 kHz	100 μH	1 mH	10 mH	100 mH	1 H	10 H	0.2 μH	
Resistance	All	10 Ω	100 Ω	1 kΩ	10 kΩ	100 kΩ	1 MΩ	10 mΩ	±(2% of reading or 0.1% of full scale) ± $\frac{4\pi f_{kHz} Q_x}{100}$ %*
Q		∞ to 1, direct reading at above frequencies Largest scale reading: 1000						0.9	1/Q accuracy = ± 2% ±0.001 ±0.0005 f_{kHz}*
Max rms volts		12.5	125	1250	1250	1250	1250		
Min rms volts for 1% accuracy (internal detector)	50, 60 Hz	0.025	0.25	2.5	2.5	2.5	2.5		
	1 kHz	0.006	0.06	0.6	0.6	0.6	0.6		
Max rms amperes**		7	7	7	2	0.7	0.2		
with extension unit†		50	50	50					

* The frequency-error term is 5 times larger on highest L range.

** Max rms current = $\sqrt{I^2_{dc} + I^2_{ac}}$

† 1633-P1 Range-Extension Unit contains a 0.1-Ω resistor, which you connect externally to shunt R_S (on the 3 lowest bridge ranges). Inductance and resistance values are reduced by a factor of 10.

Generator: External only (not supplied). For optimum performance when dc bias is used, ac supply must be able to withstand large dc currents in output circuit, and dc supply large ac currents. For dc bias, use 1265-A Adjustable DC Power Supply, 200 W; over the audio-frequency range, use 1308-A Audio Oscillator and Power Amplifier, 200 VA.

Detectors: INTERNAL: Selectively tuned to 50, 60, 100, 120, 400, 800 Hz, 1, 10, and 15.75 kHz; response varies < 3 dB for frequency components within ±1% of the nominal. Response at 2nd harmonic is typically 50 dB lower. EXTERNAL: Use the 1232-A Tuned Amplifier and Null Detector, which is tunable continuously, 20 Hz to 20 kHz.

Available: 1633-P1 Range-Extension Unit, 1232-A Tuned Amplifier and Null Detector, 1308-A Audio Oscillator and Power Amplifier.

Power: 105 to 125 V or 210 to 250 V, 50 to 60 Hz, ≈ 6 W.

Mechanical: Rack-bench cabinet. DIMENSIONS (wxhxd): Bench, 19x12.75x10.25 in. (483x324x260 mm); rack, 19x12.25x8.75 in. (483x311x222 mm). WEIGHT: 31 lb (14 kg) net, 48 lb (22 kg) shipping.

Description	Catalog Number
1633-A Incremental-Inductance Bridge	
115-V Bench Model	**1633-9801**
115-V Rack Model	**1633-9811**
230-V Bench Model	**1633-9802**
230-V Rack Model	**1633-9812**

Warranty

GenRad

We warrant that this product is free from defects in material and workmanship and, when properly used, will perform in accordance with applicable GenRad specifications. If within one year after original shipment it is found not to meet this standard, it will be repaired or, at the option of GenRad, replaced at no charge when returned to a GenRad service facility. Changes in the product not approved by GenRad shall void this warranty. GenRad shall not be liable for any indirect, special, or consequential damages, even if notice has been given of the possibility of such damages.

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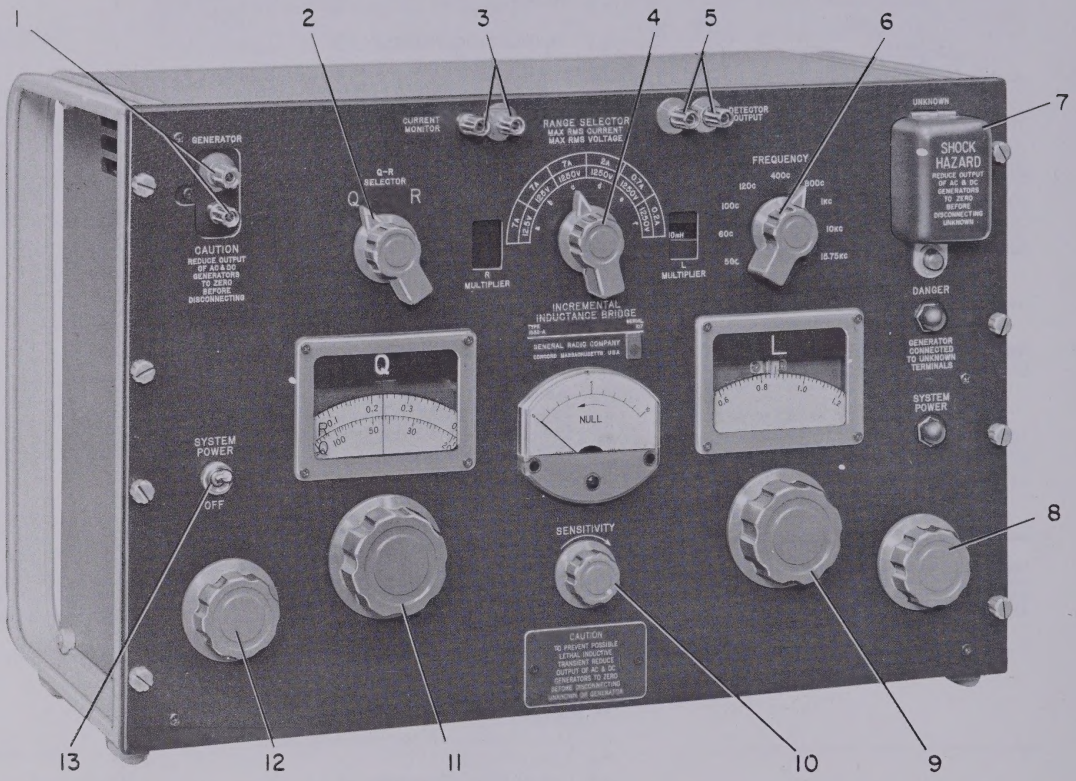


Figure 1-1. Panel view of Type 1633-A Incremental Inductance Bridge.

READ COMPLETE INSTRUCTIONS BEFORE OPERATING BRIDGE.

WARNING

It is possible to apply large values of current and voltage to an inductor through the Type 1633-A Incremental Inductance Bridge. These can be dangerous to both operator and equipment if the instructions are not followed.

When the current through an inductive circuit is suddenly interrupted, a voltage transient occurs across the open circuit. To avoid shock hazard to the operator and/or damage to the bridge, the outputs of the ac and dc generators must be reduced to zero before connections are made to the UNKNOWN or to the GENERATOR terminals, and before the setting of the RANGE SELECTOR switch is changed.

The bridge is equipped with several safety features that are intended to protect the equipment and to help the operator avoid mistakes. The UNKNOWN terminals are protected by a hinged safety cover which, when opened, effectively shorts the GENERATOR terminals of the bridge and discharges any energy stored in the inductor. The external generator should be fused or otherwise protected so that it will not be damaged by the effect of this short circuit.

The leads to the unknown should always be connected and disconnected at the bridge terminals, not at the load.

As an added protection, a red panel light indicates when the generator is connected to the UNKNOWN terminals.

SECTION **1**

INTRODUCTION

1.1 PURPOSE.

The Type 1633-A Incremental Inductance Bridge (Figure 1-1) is designed to measure inductors and resistors, both linear and nonlinear, over a wide range of ac and dc signal levels. Direct-reading measurements can be made over a broad frequency range.

1.2 DESCRIPTION.

1.2.1 GENERAL. The Type 1633-A Incremental Inductance Bridge includes a unique bridge circuit and a highly selective detector. It is direct reading in series inductance (L_S) and either series resistance (R_S) or storage factor (Q) at nine commonly used frequencies between 50 Hz and 15.75 kHz. It features single-knob controls for the measurement of L, R, or Q, and combines simplicity of operation with very high voltage- and current-handling capabilities. The signal losses in the bridge are small; thus the voltage and current through the unknown are nearly identical in both amplitude and waveform to the respective voltage and current applied at the GENERATOR terminals. In many instances measurements can be made while the inductor is actually operating in its circuit.

The bridge is designed primarily for the measurement of iron-core inductors such as transformers and chokes. It is also suitable for the measurement of other nonlinear devices, such as solid-state rectifiers and Zener diodes. The errors resulting from harmonics generated by nonlinear components are eliminated by the sharp tuning of the built-in null detector.

An oscilloscope connected to the CURRENT MONITOR panel terminals can be used conveniently to monitor the magnitude and waveform of the current through the unknown.

1.2.2 CONTROLS, INDICATORS, AND CONNECTORS.

Fig. 1-1 Ref.	*Ref. Designator*	*Name*	*Type*	*Function*
1	J101, 102	GENERATOR	Pair of Type 938 Binding Posts	Connection for external generator.
2	S1	Q-R SELECTOR	2-position selector switch	Selects type of indication of loss component of unknown.
3	J103,104	CURRENT MONITOR	Pair of Type 938 Binding Posts	Connection for external indicator, to monitor current in unknown impedance.
4	S2	RANGE SELECTOR MAX RMS CURRENT MAX RMS VOLTAGE	6-position selector switch	Selects resistance and inductance ranges. Also designates maximum allowable values of voltage and current for the selected bridge arm.
5	J105,106	DETECTOR OUTPUT	Pair of Type 938 Binding Posts	Connection for external detector.
6	S3	FREQUENCY	9-position selector switch	Selects frequency at which bridge is direct reading and to which the detector is tuned.
7	J107, 108	UNKNOWN	Pair of Type 938 Binding Posts, under safety cover	Connection for unknown impedance.
8	R102		Vernier control for item 9	Adjusts bridge balance.
9	R102	L	Continuous rotary control with dial	Adjusts bridge balance.
10	R407, 408	SENSITIVITY	Continuous rotary control	Adjusts sensitivity of detector.
11	R106	R–Q	Continuous rotary control with dial	Adjusts bridge balance.
12	R106		Vernier control for item 11	
13	S101	SYSTEM POWER	2-position toggle switch	Controls power to bridge and to all instruments connected through power receptacles on rear panel of bridge.

The following connectors are located on the rear panel of the bridge (see Figure 6-1):

1	SO103		4-pin multipoint connector	Connection for external generator.
2	SO101 SO102		Female power-line connectors	Line-voltage connections for external generators.
3	PL101		Male power-line connector	Line-voltage connection for bridge.

1.3 SYMBOLS, ABBREVIATIONS, AND DEFINITIONS.

The following symbols, abbreviations, and definitions are used on the panel of the Type 1633-A Incremental Inductance Bridge and throughout these Operating Instructions:

C -- capacitance, (⊣⊢)
C_s -- series capacitance
C_p -- parallel capacitance
L -- inductance (∿∿∿)
L_s -- series inductance
L_p -- parallel inductance
R -- resistance, the real term of a complex impedance (—∿∿—)
R_s -- series resistance
R_p -- parallel resistance
X -- reactance, the imaginary term of a complex impedance
Z -- impedance
Q -- storage factor $= \frac{X}{R} = \frac{1}{D}$

for inductors $\frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$

D -- dissipation factor $= \frac{R}{X} = \frac{1}{Q}$

ω -- angular frequency $= 2\pi f$
Ω -- ohm, a unit of resistance, reactance, or impedance
kΩ -- kilohm 1 kΩ = 1000 ohms
MΩ -- megohm 1 MΩ = 1 x 10^6 ohms
mΩ -- milliohm 1 mΩ = 0.001 ohm
μf (or μF) -- microfarad, a unit of capacitance
nf -- nanofarad, 1 nf = 0.001 μf
pf -- picofarad, 1 pf = 1$\mu\mu$f = 1 x 10^{-6} μf
h (or H) -- henry, a unit of inductance
mh (or mH) -- millihenry, 1 mh = 0.001 h
μh -- microhenry, 1 μh = 1 x 10^{-6} h

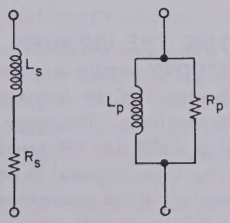


Figure 1-2. Equivalent circuits for a complex impedance.

1.4 SERIES AND PARALLEL COMPONENTS.

An impedance that is neither a pure resistance nor a pure reactance can be represented by either a series or a parallel combination of resistance and reactance. The value of resistance and reactance used in the equivalent circuit depends on whether a series or a parallel combination is used. Equivalent circuits are shown in Figure 1-2.

$$Z = R_s + j\omega L_s = \frac{j\omega L_p R_p}{R_p + j\omega L_p} = \frac{R_p + jQ^2\omega L_p}{1 + Q^2}$$

$$Q = \frac{1}{D} = \frac{\omega L_s}{R_s} = \frac{R_p}{\omega L_p}$$

$$L_s = \frac{Q^2}{1 + Q^2} L_p = \frac{1}{1 + D^2} L_p$$

$$L_p = \frac{1 + Q^2}{Q^2} L_s = (1 + D^2) L_s$$

$$R_s = \frac{1}{1 + Q^2} R_p;\ R_p = (1 + Q^2) R_s$$

$$R_s = \frac{\omega L_s}{Q};\ R_p = Q\omega L_p$$

The Type 1633-A Incremental Inductance Bridge measures L_s, R_s, and Q directly. Other forms of representation can be calculated from the above equations.

1.5 ACCESSORIES SUPPLIED.

The instrument is supplied with a power-connector in conformance with the International Electrotechnical Commission publication 320. The 3 flat contacts are surrounded by a cylindrical plastic shroud that eliminates the possibility of electrical shock whenever the power cord is being unplugged from the instrument. The connector is a 3-pin grounding-type rated for 250 V at 6A. It also meets requirements of Underwriter's Laboratories in the U.S. and the Canadian Standards Association. The receptacle accepts power cords fitted with the Belden type SPH-386 connector. The power cord (GR P/N 4200-9625) is a 7-ft, 3-wire, 18-gauge unit with connector bodies molded integrally with the jacket. The connector at the power-line end is a stackable hammerhead design that conforms to the "Standard for Grounding Type Attachment Plug Caps and Receptacles," ANSI C73.11-1963.

1.6 MOUNTING.

The instrument is available either for bench mounting, or for relay-rack mounting. The rack version includes mounting brackets (P/N 7863-9678). These brackets permit either cabinet or instrument to be withdrawn independently of the other. Installation instructions accompany these brackets.

SECTION **2**

OPERATING PROCEDURE

2.1 INSTALLATION.

2.1.1 POWER CONNECTIONS. Connect the instrument to a suitable power source, as indicated on the plate near the power receptacle on the rear panel (115 or 230 volts, 50 - 400 Hz). Two power receptacles for the generators are provided on the rear panel, so that power to all instruments can be controlled by the SYSTEM POWER switch on the front panel of the Type 1633-A. The current available at the receptacles is six amperes at 115 volts or three amperes at 230 volts, and is limited by the rating of the switch.

2.1.2 GROUNDING. To minimize the possibility of errors from power-line hum and of shock hazard when high-power sources are used, the instrument should be connected to a good ground. A three-wire power cord has been provided for this purpose, but any of the panel ground terminals can be used.

2.1.3 MOUNTING. The instrument can be operated in any position. Care should be taken to avoid using the bridge in the presence of large external fields of the same frequency as that used in the measurements.

2.2 USE AT FREQUENCIES INDICATED ON PANEL (INTERNAL DETECTOR).

2.2.1 GENERAL. The internal detector can be used at any one of the nine frequencies indicated on the panel FREQUENCY switch: 50, 60, 100, 120, 400, 800 Hz, 1, 10, or 15.75 kHz.

Install the bridge as noted in paragraph 2.1.

2.2.2 GENERATOR REQUIREMENTS. The bridge will operate with generator levels of 6 mv to 1250 volts and 0 to 7 amperes. A single generator usually will not cover this entire dynamic range. The generators of the Type 1630-AV Measuring Assembly (paragraph 1.7) provide signal levels up to 200 volt-amperes ac and 200 watts dc over a wide range of impedances; they were designed specifically to complement the features of the bridge. However, other generators that satisfy the desired excitation requirements can be used. Any combination of ac and dc generators within the power ranges noted above the RANGE SELECTOR switch on the front panel can be connected to the GENERATOR terminals.

Two methods of superimposing ac and dc signals, in series or in parallel, are possible (see Figure 2-1). With either method, each supply must be designed for use with the other and with the reactive load. In many instances, the unknown inductor or resistor can be measured under actual operating conditions, with its own power sources and circuit components (refer to paragraph 5.5).

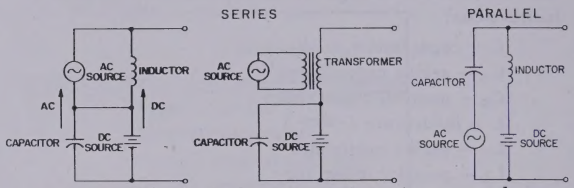


Figure 2-1. Methods of superimposing ac and dc signals. The additional components serve to isolate the two sources.

2.2.3 RECOMMENDED GENERATORS. For general-purpose measurements, to 200 volt-amperes, ac and dc, the Type 1308-A Audio Oscillator and Power Amplifier, and the Type 1265-A Adjustable DC Power Supply are recommended. For measurements at levels to one watt, with signal levels up to 100 volts (open circuit) or four amperes (short circuit), the Type 1311-A Audio Oscillator is suitable. At higher power levels, a General Radio Variac® Autotransformer and an isolation transformer can be used. The latter is necessary to avoid errors due to circulating ground currents.

2.2.4 CONNECTING THE GENERATORS. TURN ALL GENERATOR OUTPUTS TO ZERO. Then connect them to the GENERATOR terminals of the bridge. Either the binding posts on the front panel or the multipoint connector on the rear panel can be used. A cap is provided to cover the front-panel GENERATOR terminals when the rear connector is used, to avoid possible shock hazard, since these terminals carry the full generator voltage.

2.2.5 CONNECTING THE UNKNOWN. Press the button below the UNKNOWN terminals to open the protective cover. Attach the leads of the inductor to be measured to the UNKNOWN terminals. The upper terminal is connected to the high GENERATOR terminal and has the higher voltage. The lower terminal is near ground potential. (Neither terminal of the unknown can be connected externally to the bridge ground; refer to paragraph 5.2.) Close the cover and lock it by again pressing the button. The DANGER warning light will now light.

2.2.6 SETTING THE PANEL CONTROLS.

2.2.6.1 Q-R SELECTOR Switch. Set the Q-R switch to either Q or R, as desired. If the resistance of the unknown is larger than the reactance (Q is less than 1),

the R scale must be used $\left(Q = \frac{2\pi fL}{R}\right)$. If the Q of the unknown is greater than unity, either the R or the Q scale can be used. The Q scale provides greater resolution for high-Q inductors.

2.2.6.2 FREQUENCY Switch. Set the FREQUENCY switch to the frequency of measurement. For use at frequencies other than those indicated on the panel, refer to paragraph 2.3.

2.2.6.3 RANGE SELECTOR Switch. Set the RANGE SELECTOR switch to the approximate value of the unknown, as indicated in the MULTIPLIER windows. If the approximate value is not known, set the L control to mid-scale, apply a small amount of ac voltage, and adjust the RANGE SELECTOR switch until minimum reading of the NULL indicator is obtained.

2.2.7 BALANCING THE BRIDGE.

a. Turn on the generators. Do not exceed the voltage or current rating (ac or dc) indicated by the selected position of the RANGE SELECTOR control.

b. Tune the generator frequency for maximum deflection of the panel meter.

c. Adjust the R-Q and L controls until the bridge is balanced, as indicated by a null on the meter. When nonlinear unknowns are measured, it is possible for harmonics of the input signal to saturate the input stages of the null detector and cause errors. Therefore, the SENSITIVITY control of the detector should be advanced only as much as necessary for these measurements. When the balancing procedure has been completed, decrease the setting of the SENSITIVITY control slightly. If the pointer of the meter moves up scale, the original setting of the SENSITIVITY control was too high and the bridge must be rebalanced at a somewhat decreased setting. The null detector is designed to permit at least a 1% balance under the worst possible conditions, with the proper setting of the SENSITIVITY control.

To obtain the series inductance and resistance of the unknown, multiply each dial reading by the corresponding MULTIPLIER in the panel window. For example, if the L dial indicates 7 and the L MULTIPLIER window indicates 10 mh, the unknown has an inductance of 70 mh. The greatest accuracy is obtained when the RANGE SELECTOR switch is set so that, at balance, either the R or the L dial reads greater than 1.0. The value of Q is read directly, without the use of a multiplier.

CAUTION: Reduce the generator outputs to zero before changing connections or ranges, and make all connections and disconnections to the unknown at the UNKNOWN terminals on the panel, to reduce possible shock hazard.

2.2.8 ACCURACY. At 1 kc or below, the accuracy of the L dial is ±1% of the reading, or ±0.1% of full scale, whichever is the greater. This corresponds to approximately ±1/16 inch at any point on the L scale. The accuracy of the R-Q dial is ±2% of the reading, or ±0.1% of full scale, whichever is the greater. This corresponds to approximately ±1/8 inch at any point of the R or Q scale. The effects of residual impedances are covered in paragraph 2.4.3.9.

At higher frequencies an additional error for L, $\left(\frac{2\pi}{100} \times \frac{f_{kHz}}{Q_x}\right)$, may be important with low-Q coils. With high-Q coils, the error for R, $\left(\frac{1}{2\pi} Q_x f_{kHz}\right)$, may be important.

2.2.9 CURRENT MONITOR TERMINALS. The CURRENT MONITOR terminals are connected across R_b, Figure 2-2. The voltage across these terminals is proportional to the current through the unknown inductor, so that an oscilloscope or similar instrument can be used to monitor this current. The value of resistor R_b is a function of the RANGE SELECTOR switch setting, as given in Table 1.

The open-circuit voltage across the CURRENT MONITOR terminals is the difference between the voltage applied across the GENERATOR terminals and that applied across the UNKNOWN terminals. The voltage is small and is usually negligible if the impedance of the unknown is greater than 100 ohms and if the balance can be obtained above 1.0 on either the R or L scale.

2.2.10 DETECTOR OUTPUT TERMINALS. The detector signal is available at the DETECTOR OUTPUT terminals, so that the signal can be monitored by an oscilloscope or other indicating device, or so that an externally tuned detector can be used. An internal link connects these terminals to either of two points in the internal detector. The FLAT output is taken at the output of the internal low-noise preamplifier; the TUNED output is taken at the output of the frequency-selective amplifier.

TABLE 1

VALUE OF RESISTOR R_b FOR EACH RANGE SELECTOR SWITCH SETTING.

RANGE SELECTOR SWITCH SETTING	R_b - OHMS (±1/4%)
a - c	0.9
d	9.0
e	90.0
f	900.0

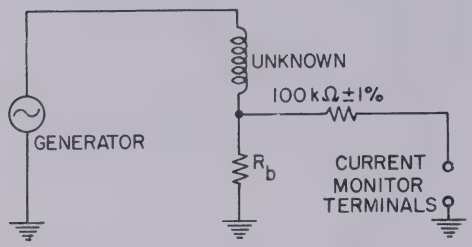


Figure 2-2. Connections to the CURRENT MONITOR panel terminals.

To change the position of the internal link, remove the thumbscrews at the rear of the bridge and slide the instrument about two inches out of its cabinet. Locate the terminal strip behind the DETECTOR OUTPUT terminals. The metal link should connect terminals 68 and 67 for the TUNED output, and terminals 67and 66 for the FLAT output. In either position of the link, the internal detector functions normally. However, when the link is in the FLAT position, the internal detector is more sensitive to stray signal pickup on the DETECTOR OUTPUT terminals; therefore these terminals and the external leads should be shielded or shorted. This precaution is not necessary if the link is left in the TUNED position.

2.3 USE AT OTHER FREQUENCIES.

2.3.1 EXTERNAL DETECTOR. Should measurements be required at a frequency other than one of the nine provided, an external detector, such as the General Radio Type 1232-A Tuned Amplifier and Null Detector, can be used.

Make certain that the DETECTOR OUTPUT terminals are connected in the FLAT position, as described in paragraph 2.2.10, and are connected to the input terminals of the external detector with a shielded patch cord. Insulate the detector case from the case of the bridge to avoid ground-loop problems and place the detector several feet from the generator current path to avoid magnetic pickup. The SENSITIVITY knob of the bridge controls the detector output signal and should be set so that the signal is less than 1 millivolt. Since the external detector does not affect the operation of the internal detector,it may remain connected even when the internal detector is being used.

2.3.2 SETTING THE CONTROLS. Set the FREQUENCY switch at some engraved value near the frequency of measurement. The 100 Hz, 1 kHz, and 10 kHz positions are generally the most convenient, since the readings of the Q dial must be multiplied by a factor involving the setting of the FREQUENCY switch.

$$Q = Q_o \times \frac{f}{f_o}, \text{ where}$$

Q = Q of unknown at frequency f;
Q_o = reading of Q dial at balance;
f = generator frequency;
f_o = setting of FREQUENCY switch.

With these modifications, the operation of the bridge is the same as that noted in paragraph 2.2.

For continued use at a frequency other than those indicated, a modification of the internal frequencies may be desirable (refer to paragraph 5.9).

2.4 POSSIBLE SOURCES OF ERROR.

2.4.1 GENERAL. Interaction between the bridge and other parts of the measurement assembly can produce certain problems. Particular care is necessary at high power levels. Some common sources of error that may be encountered are listed below. If other problems arise or a malfunction of the bridge is suspected, refer to the paragraphs on Service and Maintenance, Section 6.

2.4.2 BALANCE NOT OBTAINABLE.

2.4.2.1 Q Range is Exceeded. When L and Q are measured, the Q of the unknown may be less than unity. Make the balance in terms of L and R.

2.4.2.2 Measurement Frequency Higher than Resonant Frequency of Inductor. Above the frequency at which the inductor resonates with its stray capacitance, the impedance is capacitive. The balance will appear to be below zero on the L control. Use a lower frequency.

2.4.2.3 Low Sensitivity. This may be caused by:

a. Open safety cover over UNKNOWN terminals. With this cover open, the generator terminals are shorted. Close the cover before making measurements.

b. Low generator voltage. The bridge is useful over a very wide range of generator voltages. Typical values of the minimum signal for which a balance to a 1% precision can be obtained are listed below:

RANGE	50 – 60 Hz	1 kHz
a	25 mv	6
b	250 mv	60 mv
c - f	2500 mv	600 mv

c. Blown generator fuse. Replace the fuse (10 amperes) on the generator side of the rear panel of the bridge.

2.4.3 READING APPEARS IN ERROR.

2.4.3.1 Measurement Frequency Approaches Resonant Frequency of Inductor and Its Stray Capacitance. When the frequency of operation is within a factor of 10 below

the resonant frequency of the inductor, the effective inductance will be higher than the low-frequency inductance. The following correction can be applied:

$$\text{From the dial reading subtract} \left(\frac{f}{f_o}\right)^2 L_x, \text{ where}$$

f = frequency of measurement,
f_o = resonant frequency of inductor.

2.4.3.2 Current Induced in Bridge Circuit by Magnetic Field of Unknown Inductor. To check for this condition, change the physical orientation of the inductor with respect to the bridge.

2.4.3.3 Hum Pickup Due to Power Line. An error due to hum pickup may be encountered when measurements are made at the power-line frequency. To test for this condition, turn the generator output to zero after a balance has been made and short the generator terminals at the bridge. There should be negligible indication on the null detector. Hum signals present in the bridge due to internal sources will not cause an error if the balance can be made with the SENSITIVITY control less than 3/4 clockwise. At higher sensitivities, a small error, whose magnitude depends on the settings of the various controls, can occur if the generator signal level is very low (refer to paragraph 2.4.2.3). The test outlined above should be made if this error is suspected.

2.4.3.4 Bridge Measures Series Inductance; Parallel Inductance is Needed. In this case a correction is sometimes necessary. Refer to the chart inside the back cover, or to paragraph 1.4. When the Q of the unknown is greater than 10, the correction is less than 1%.

2.4.3.5 SENSITIVITY Control Set Too High. When components with unsymmetrical, nonlinear characteristics are measured (such as when a large dc bias current is applied to an iron-cored coil), large odd and even harmonics can be produced which mix to give a stray fundamental component if the signals are large enough to cause clipping in the detector circuits. To test for this problem, reduce the setting of the SENSITIVITY control after a balance has been obtained. The null should not change (refer to paragraph 2.2.7). The detector circuits are designed with sufficient dynamic range to allow at least a 1% balance under the worst possible conditions, with the proper setting of the SENSITIVITY control.

2.4.3.6 Ground Currents. If the bridge and the generator are connected with multiple ground leads, the potential drop in the leads can cause an error. Unless the generator current enters and leaves the bridge by either of the two sets of GENERATOR terminals provided, the magnetic field of the loop produced may induce stray currents in the bridge circuits. This problem is primarily important at high currents and high frequencies. To test for this, reduce the generator output to zero; then short the GENERATOR terminals at the bridge after a balance has been made and adjust the ac generator so that the current flowing in the generator circuit is the same as during the measurement. The null detector should show negligible deflection.

2.4.3.7 Results Not Repeatable. When ferromagnetic coils are measured, the inductance depends on the ac- and dc-signal levels and on the previous excitation history of the core. Also, results of a series of measurements made by progressively increasing the excitation

TABLE 2

APPROXIMATE VALUE OF EXTERNAL STRAY CAPACITANCE, C_b, FOR ONE-PERCENT INDUCTANCE ERROR.

RANGE SELECTOR SWITCH SETTING	FREQUENCY SWITCH SETTING		
	50 Hz to 120 Hz	400 Hz to 1 kHz	10 kHz to 15.75 kHz
a	1 μf	0.1 μf	0.01 μf
b	1 μf	0.1 μf	0.01 μf
c	1 μf	0.1 μf	0.01 μf
d	0.1 μf	0.01 μf	1000 pf
e	0.01 μf	1000 pf	100 pf
f	1000 pf	100 pf	10 pf

will not necessarily be the same as those made by decreasing the excitation, because of the hysteresis effect (refer to paragraph 4.1.1). Effects of internal heating in the unknown should also be considered. Specifications of the value of inductance should include all of these factors.

2.4.3.8 External Stray Capacitance from Low UNKNOWN Terminal to Ground. This capacitance, C_b, shunts the ratio arm, R_b. The following corrections can be applied:

L—from the bridge reading subtract $R_x R_b C_b$.

R—to the bridge reading add $L_x R_b C_b \omega^2$.

(See Table 1 for value of R_b.)

Table 2 gives the approximate capacitance that will produce a one-percent error.

It may be helpful to reverse the connections to the unknown, since capacitance from the high UNKNOWN terminal to ground does not cause an error.

2.4.3.9 Effects of Lead Resistance and Inductance. When small inductances or resistances are measured, the impedance of the connecting leads and the bridge residual impedances can be important. To eliminate these factors:

a. Measure the unknown in the normal manner.

b. Without disturbing the connecting leads, connect a low-impedance, short circuit across the terminals of the unknown and measure the resistance and inductance of the leads. Subtract these values from those obtained in a, above.

The magnitude of the lead inductance can be estimated as 0.025 μh per inch of each lead, if the area of the loop formed is small. The residual impedances of the bridge at the terminals are approximately 0.2 μh and 1 mΩ.

In addition, there is an internal stray capacitance across the bridge UNKNOWN terminals of approximately 2 pF. This is normally not important, because the stray capacitance of most inductors is greater than this. The terminal stray capacitance will cause the bridge to read high by approximately

$$\frac{8}{1000} L_x f^2 \text{ percent}$$

where L is in henrys and f is in kHz.

2.5 ACCURACY OF MEASUREMENTS.

The basic bridge accuracy is 1% for inductance and 2% for both resistance and Q. The resolution of the controls adds additional terms: ±0.1% of full scale for L and R and ±.001 for $\frac{1}{Q}$. At higher frequencies additional errors can be caused by the phase angle of the arms of the bridge. These error terms are:

$\pm\left(\frac{2\pi}{100} \times \frac{f_{kHz}}{Q_x}\right)\%$ for inductance,

$\pm\left(\frac{4\pi Q x f_{kHz}}{100}\right)\%$ for resistance, and

$\pm .0005 f_{kHz}$ for Q, on all ranges except the highest, where the terms are five times larger.

These terms are important when high-Q inductors or low-Q resistors are measured. The highest range is not often used at high frequencies, since the stray capacitance of large inductors limits their use to low frequencies. The accuracy of Q applies when the inductance reading is above one-tenth of full scale. Below this value, a lower range should be used.

2.6 TYPE 1630-AV INCREMENTAL INDUCTANCE MEASURING ASSEMBLY.

The Type 1265-A Adjustable DC Power Supply and the Type 1308-A Audio Oscillator and Power Amplifier have been designed primarily for use with the Type 1633-A Incremental Inductance Bridge. These units are available as a complete incremental-inductance-measuring assembly, Type 1630-AV (see Figure 2-3).

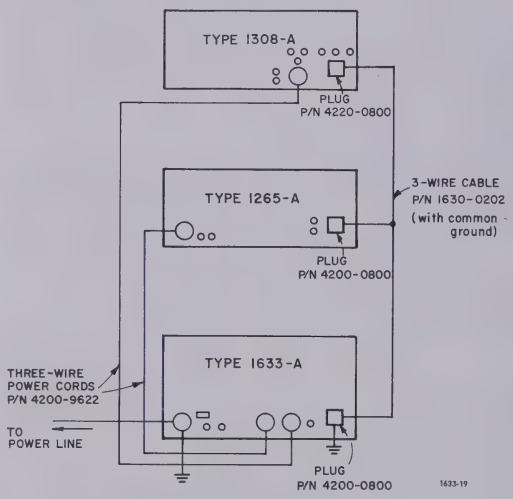


Figure 2-3. Block diagram of Type 1630-AV Inductance-Measuring Assembly showing interconnections.

The Type 1265-A Adjustable DC Power Supply can be used as a source of either constant voltage or constant current. The output is continuously adjustable and is monitored by front-panel voltage and current meters. In addition to its use as an accessory for the Incremental Inductance Bridge, the Type 1265-A is useful as a general-purpose power supply.

The Type 1308-A Audio Oscillator and Power Amplifier provides a source of voltage and current with an output frequency that is continuously variable between 20 Hz and 20 kHz. In addition to its use as an ac bridge generator it is useful as a general-purpose power oscillator or power amplifier.

2.7 TYPE 1633-P1 RANGE-EXTENSION UNIT.

The Type 1633-P1 Range-Extension Unit can be used with the Type 1633-A Incremental Inductance Bridge to extend the current ratings to 50 amperes. It uses a 250-watt, 0.1-ohm resistor, which is placed in parallel with one of the bridge arms (R_B). The schematic diagram for the unit is shown in Figure 2.4.

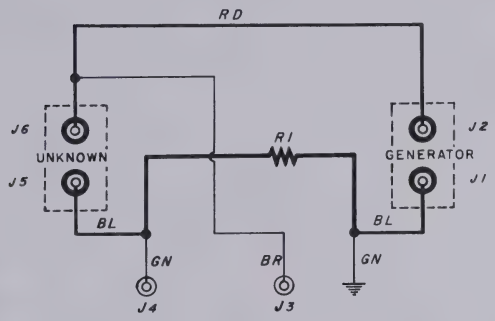


Figure 2-4. Schematic diagram for Type 1633-P1 Range-Extension Unit.

High-current terminals capable of accommodating leads up to ¼ inch in diameter are provided on the Type 1633-P1 for the generator and unknown. The cable supplied is used to connect the extension unit to the bridge. Make certain that the ground strap is connected to the panel by means of the screw provided. A diagram showing the proper connections is shown in Figure 2-5. When the Type 1633-P1 is used, any other connections to the rear or panel generator terminals on the Type 1633-A must be removed.

When the range-extension unit is connected, the operation of the bridge is the same as listed in Section 2 of the Type 1633-A Instruction Manual except that only the a, b, and c ranges can be used. Bridge inductance and resistance readings should be multiplied by 0.1.

With the cable supplied (P/N 1633-2770), the use of the Type 1633-P1 at frequencies up to 400 Hz can

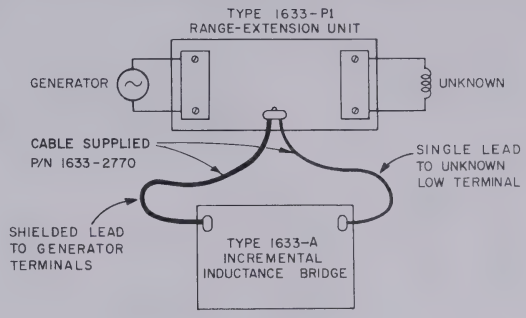


Figure 2-5. Connections from the range-extension unit to the bridge.

cause up to 1% additional error in the bridge readings. The temperature coefficient of the resistor is less than 20 ppm per degree Centigrade.

For higher accuracy, a correction factor can be obtained by measuring a standard inductor or resistor using the Type 1633-P1. The correction factor can be applied to inductance and resistance readings, but not to the Q readings.

Any current up to 30 amperes continuous or 50 amperes intermittent, ac or dc, can be used. Continuous operation at 50 amperes without forced-air cooling will result in excessive panel temperature, which could affect the paint and insulation.

The maximum voltage that can be applied to the generator terminals is that shown over the bridge RANGE SELECTOR.

The voltage and currents that can be applied to this instrument can constitute a serious shock hazard, and adequate safety precautions should be taken. At high currents the case and panel of the Type 1633-P1 can be very "hot" and the operator should avoid touching the unit.

COMPONENT LIST

Name	*Part Number*
Resistor:	
R1 0.1 Ohm ±.25%	1633-0440
Binding Posts:	
J4	0938-4146
J3	0938-4146
High Voltage Terminals:	
J1 and J2	1633-3080
J5 and J6	1633-3080

SECTION **3**

PRINCIPLES OF OPERATION

3.1 GENERAL.

The characteristics of iron-cored coils are usually nonlinear. To measure the L or Q of such a coil, the direct current through the coil and the ac voltage across it must be specified, or the measured values are meaningless. Conventional inductance bridges are intended for the measurement of linear inductors, whose characteristics are practically independent of the ac voltage applied and do not, in general, carry any direct current. Although these bridges can be used to measure incremental inductance, their ratio arms are not designed to carry appreciable amounts of direct current. It is not usually convenient to apply a specified ac voltage across the unknown.

The Type 1633-A Incremental Inductance Bridge measures inductance without appreciably affecting the operating conditions. Since practically all of the voltage and current supplied by the generator is applied to the unknown, it is a simple procedure to set the appropriate levels. With this bridge, it is possible to measure the characteristics of the unknown under actual operating conditions.

A simplified schematic diagram showing the basic parts of the Type 1633-A is shown in Figure 3-1.

3.2 BRIDGE CIRCUIT.

The bridge circuit used in the Type 1633-A is unusual in that it contains three highly stable amplifiers that isolate certain parts of the circuit and perform functions that would be difficult to accomplish by other means.

The four arms usually associated with an impedance bridge are the unknown, and resistors R_a, R_b, and R_c, Figure 3-1. The current through an inductive unknown develops a voltage across R_b. (The value of R_b is usually small compared with the unknown impedance.) A fraction, α, of this voltage, determined by the setting of the L balance control, is present at the output of the L isolation amplifier and causes a current to flow in the standard capacitor, C (see Figure 3-2). This current is in phase with the generator voltage.

On the other side of the bridge, a divider formed by R_a and R_c presents a voltage, proportional to the generator voltage, to the high input impedance of the operational amplifier. The amplifier has a very constant transconductance, so that its output current is proportional to the input voltage and is opposite to it in phase. At balance, the current through the standard capacitor, C, is equal in magnitude and opposite in phase to the current from the amplifier. The net detector current, therefore, is zero and the meter indicates a null.

This circuit has several advantages over the more commonly used passive bridge circuits. Ordinarily, the current through the standard capacitor is changed by varying the capacitance. The convenience of single-knob operation usually is limited to the use of variable air capacitors of values up to a few thousand picofarads. For larger values, switched decades of capacitors must be employed. In the Type 1633-A Incremental Inductance Bridge, however, a single, large, fixed capacitor is used. The current through this capacitor is varied by changing the voltage developed across it. This is ac-

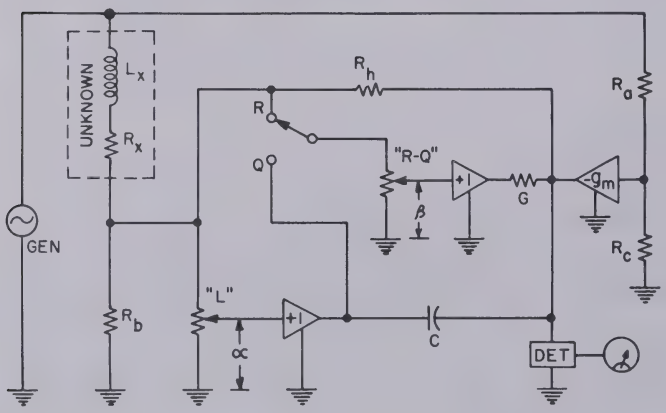


Figure 3-1. Elementary schematic diagram for Type 1633-A Incremental Inductance Bridge.

complished by adjustment of the L balance control. Thus the speed and convenience of single-knob control and the use of a large standard capacitor are both possible.

All resistors in the bridge circuit have fixed values and these are switched to achieve the wide range of inductance measurements. The resistor R_b can be made small and R_a very large, so that the impedance seen by the generator is very nearly equal to the impedance of the unknown. This is particularly important in measurements on nonlinear inductors, since a large voltage drop in R_b can cause the voltage waveform across the unknown inductance to differ considerably from the waveform of the signal applied to the GENERATOR terminals. Most of the power applied to these terminals is transferred to the unknown, so that very little is lost in the bridge elements.

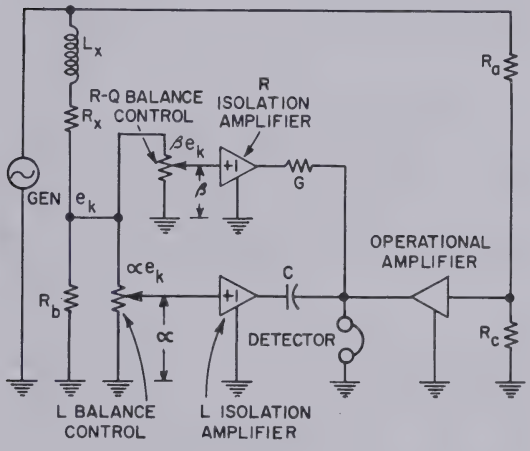


Figure 3-2. Simplified circuit for the R balance control.

The resistive component of the unknown can be measured by the adjustment of a second potentiometer that is calibrated in terms of the series resistance of the unknown. The potentiometer and a second isolation amplifier are used to control the current through the standard resistor, G, Figure 3-2. If the R potentiometer is connected across the output of the L isolation amplifier (as in Figure 3-3), the voltage at the standard resistor, G, depends upon the settings of both the R and the L potentiometers. A change in the setting of the R potentiometer changes the effective dissipation factor of the standard capacitor, so that the potentiometer dial can be calibrated in terms of the Q of the unknown inductor. The value of resistor G is changed by switching, to make the Q scale direct reading at any of nine different frequencies. This eliminates the multiplying factor that must be used with conventional bridge circuits when a frequency other than that at which the Q scale was calibrated is used.

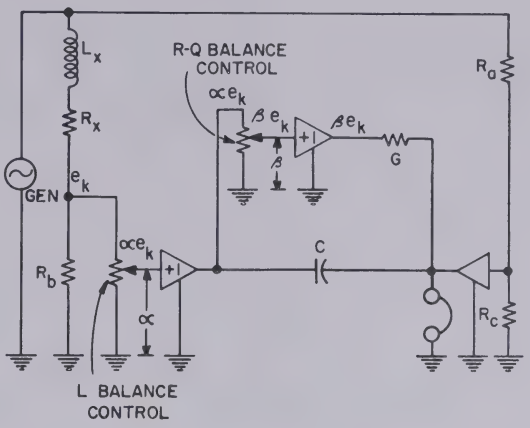


Figure 3-3. Simplified circuit for the Q balance control.

In the diagram of Figure 3-1, the following relationships are necessary for a balance:

$$L_x = \alpha C R_b R_h$$

$$R_x = \beta G R_b R_h$$

$$Q_x = \frac{\omega C}{\beta G}$$

if $$R_h = \frac{R_c + R_a}{g_m R_c}$$

where β = fractional rotation of R-Q potentiometer.

The resistor R_h compensates for the small signal-voltage drop across R_b so that the calibrations of the L and R-Q dials are directly proportional to their respective rotations.

A bridge transformer is not necessary, since the generator and the detector have a common ground. This feature avoids the possibility of stray magnetic coupling, which is particularly troublesome with measurements in the presence of large magnetic fields.

3.3 ISOLATION AMPLIFIERS.

The primary purpose of these two identical amplifiers is to isolate the bridge standards from the voltage dividers. Figure 3-4 shows a simplified schematic diagram of these amplifiers.

Three transistors are included in a feedback circuit to provide a high input impedance (approximately 10 MΩ) and to prevent loading of the calibrated poten-

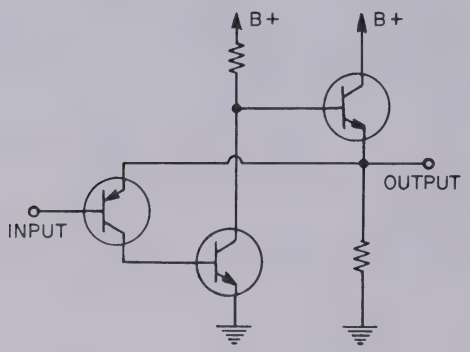


Figure 3-4. Simplified diagram of the isolation amplifier.

tiometers. The low output impedance (approximately 10 mΩ) is effectively in series with the standard capacitor and does not appreciably affect its dissipation factor. The voltage gain is very nearly unity and is very stable; thus the accuracy of the bridge is not appreciably affected.

3.4 OPERATIONAL AMPLIFIER.

This amplifier provides a current in the detector circuit that is proportional to the input voltage to the amplifier. Thus an extremely stable transconductance (g_m) is necessary. A simplified diagram of the amplifier circuit is shown in Figure 3-5. The mutual transconductance of this circuit is nearly equal to the reciprocal of the resistance of R_k (R308).

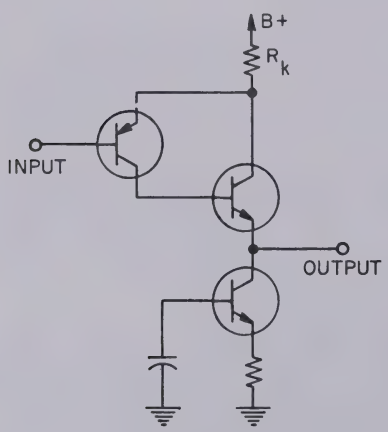


Figure 3-5. Simplified diagram of the operational amplifier.

3.5 STANDARDS.

The value of the standard capacitor, C, is determined by the setting of the FREQUENCY switch. The capacitance is changed by a factor of 10 at certain selected switch positions, to center each inductance range at or near the value most frequently encountered. This makes possible more inductance ranges over the broad frequency range. A mechanical mask over the L MULTIPLIER window indicates the correct multiplier for any combination of settings of the FREQUENCY and the RANGE SELECTOR switches. At low frequencies, General Radio polystyrene capacitors are used; a General Radio silvered-mica capacitor is used at 10 and 15.75 kHz. The balance controls are General Radio precision, wire-wound potentiometers. Ratio arms R_a and R_c (Figure 3-1) are wire-wound General Radio units, except on the f range, where R_a is a 1-megohm, precision, film resistor. The power resistors of R_b are 50-watt, 1/4%, precision, wire-wound resistors.

3.6 INTERNAL DETECTOR.

The detector is a highly sensitive and selective transistor amplifier that enables measurements to be made over a wide range of generator voltages. The amplifier is tuned to any one of nine frequencies, selected by the panel FREQUENCY switch. Selectivity is obtained from two cascaded, active, RC filters (see Figure 3-6). The response of these filters to the second harmonic of the signal is approximately 60 db below the fundamental. High selectivity is necessary, since nonlinear impedances can generate harmonics that must be attenuated sharply in the detector to eliminate errors. The filter sections are slightly stagger-tuned so that the stability of the generator frequency is not critical. The amplifier drives the panel meter, to provide a visual ac null indication. The rectifier shaping circuits give a meter reading approximately proportional to the logarithm of the input signal, thus eliminating the necessity of frequent adjustments of the SENSITIVITY control. The ac output of the detector is available at the DETECTOR OUTPUT terminals on the front panel. The output of the low-noise preamplifier is also readily accessible (refer to paragraph 2.3), to facilitate measurements at some frequency other than those provided on the FREQUENCY switch.

3.7 COMPENSATION TECHNIQUES.

To achieve the required accuracy over the wide ranges involved, numerous components have been added to the circuit to compensate for the residual impedances in the bridge elements.

The following components compensate for the inductance of the ratio arm R_b, so that it appears resistive

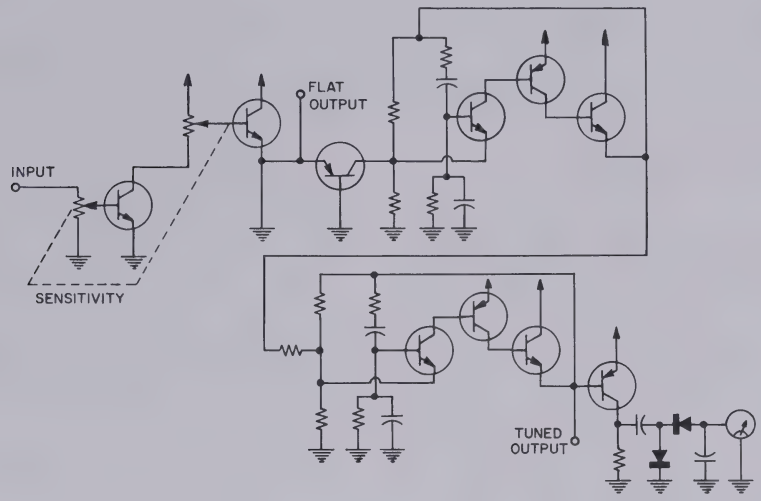


Figure 3-6. Simplified diagram of the internal detector.

over a wide frequency range: C1, C2, C3, C4, R4, R6, R8, and R10.

The following capacitors provide compensation for the lumped and distributed capacitances across R_a, to make the voltage-divider ratio independent of frequency: C5, C6, C7, C8, C9, C10, C17.

Capacitors C105 and C108 compensate for the stray capacitances in the voltage-divider potentiometers so that their input and output voltages are nearly in phase at all settings of the potentiometers.

Part of the current from the output of the isolation amplifier is coupled to the input circuit through capacitor C203 to neutralize the capacitive current from the arms of the L and R control potentiometers to ground.

3.8 PROTECTIVE DEVICES.

Because the bridge is designed to measure inductors in which the stored energy can be very large, a number of features have been incorporated in the instrument that are intended to protect the equipment and to alert the operator to possible danger. The most prominent among these is a hinged cover over the UNKNOWN terminals. A lock on this cover is mechanically connected to a switch that shorts the GENERATOR terminals to ground (through a 1-ohm, 50-watt resistor). Thus any current in the unknown inductor is discharged harmlessly, before the operator disconnects the unknown. To prevent damage to the generator due to this 1-ohm short circuit (in the event the generator has not been turned off before making connections), a 10-ampere fuse has been incorporated in the circuit. This fuse is available on the rear panel. A panel light under the UNKNOWN terminals indicates when the generator is not shorted.

It is not always possible to provide a protective device at the unknown end of any cables used to connect the unknown to the bridge. Therefore, the unknown should always be connected or disconnected at the bridge terminals.

The SYSTEM POWER switch controls the power to two receptacles on the rear panel of the instrument, so that the bridge and its generators can be conveniently controlled by the same switch. In this way the generators are also prevented from supplying power, in the event the bridge power and warning light are turned off.

If the generator connections are removed with current flowing in the circuit, the induced voltage transient is applied directly across the bridge. A Thyrite varistor (R33 on the wiring diagram, Figure) has been included to limit this voltage and to help prevent damage to the bridge.

SECTION **4**

APPLICATIONS

4.1 MEASUREMENTS OF IRON-CORED COILS.

4.1.1 GENERAL.

4.1.1.1 Definitions. A ferromagnetic core is composed of many small magnetic units, called domains, that are randomly oriented in a demagnetized sample, so that no net magnetization (B) exists. If a field (H) is applied to the core, the domains tend to line up with the field. When a sufficiently large magnetizing force is applied, substantially all the domains will be oriented in the direction of the field and no further increase in magnetization will result. This is called saturation. If the field is then decreased to zero, the domains will not necessarily redistribute themselves in a random fashion and therefore may leave a remanent magnetism. This effect is called hysteresis.

4.1.1.2 Demagnetizing. It is evident from the above that the particular state of a core depends on both the values of excitation and on the previous history of excitation. This last factor is particularly troublesome; to eliminate it, the core should first be demagnetized. An ac current of sufficient magnitude to saturate the core is applied to the coil; the current is then slowly reduced to zero (or the core is gradually removed from the field of the coil). The core is then said to be demagnetized, or brought to a symmetrically cyclically magnetized (SCM), or cyclic, condition. This procedure should be followed with any coil that has been subjected to a transient or to a direct current before an attempt is made to measure its inductance. Also, when a series of measurements is made with superposed dc in the coil, it should be made with increasing values of dc.

4.1.1.3 Commonly Used Parameters. The inductance of an iron-cored coil is proportional to the effective permeability (μ) of the core.

$$L = \frac{3.19\,\mu N^2 A \times 10^{-8}}{l}$$

where L = inductance in henrys
N = number of turns on coil
A = effective cross-sectional area of iron core in square inches
l = length of magnetic circuit in inches.

Therefore, the permeability of the core can be calculated from measurements of inductance made on the Type 1633-A. Several different permeabilities are defined as follows:

a. Normal or DC Permeability $\left(\mu_{dc} = \frac{B}{H}\right)$

A dc field is applied and the resulting magnetization is measured.

b. Incremental Permeability $\left(\mu_{\Delta} = \frac{\Delta B}{\Delta H}\right.$ where ΔH approaches 0 and H_{dc} is not 0.$\left.\right)$

To measure μ_{Δ}, superpose a small ac field (proportional to the current in the coil) upon a dc field (H_{dc}). The resultant ac induction (proportional to the voltage across the coil) is then measured. To do this, measure the inductance of the coil with a small ac signal and a dc bias applied. In general, this inductance is a function of both the ac and dc signal levels.

c. AC Permeability $\left(\mu_{ac} = \frac{\Delta B}{\Delta H}\right.$ at frequency f_o, with $H_{dc} = 0$.$\left.\right)$

This value is obtained by measurement of the inductance of a coil with ac signals applied (no dc) on a bridge with a selective detector tuned to the frequency of measurement, f_o. In general, the ac permeability is a function of the signal level and differs from the normal or dc permeability if the core is nonlinear over the range of operation, since only the fundamental component of the waveform is used is the measurement.

d. Initial Permeability $\left(\mu_i = \frac{\Delta B}{\Delta H}\right.$ where ΔH approaches 0 and $H_{dc} = 0$.$\left.\right)$

If the signal level is decreased, the ac permeability generally decreases, and at low signal levels it is proportional to H_{ac}, plus a constant (see Figure 4-1). This constant is called the initial permeability. To determine it, measure the inductance of the coil at two small values of excitation and extrapolate to zero. (This is the most easily reproducible condition for measurements and is generally used when a high degree of accuracy is required. It is the condition under which all "standard" iron-dust-cored inductors are calibrated.)

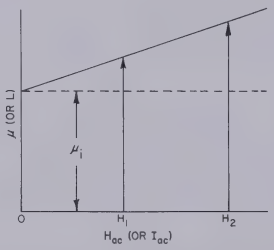


Figure 4-1. Determination of initial permeability.

4.1.1.4 Losses.

4.1.1.4.1 General. The equivalent circuit of an iron-cored coil at low frequencies is shown in Figure 4-2. Resistors R_c and R_e are nearly independent of frequency and represent, respectively, the ohmic loss in the copper and the eddy-current loss in the iron and in the copper.

4.1.1.4.2 Copper Loss. At low frequencies the resistance R_c is equal to the dc resistance of the winding. The dissipation factor corresponding to this resistance is

$$D_c = \frac{1}{Q_c} = \frac{R_c \text{ (series)}}{\omega L} = \frac{c}{f}, \text{ where c is a constant.}$$

D_c is inversely proportional to the frequency.

4.1.1.4.3 Eddy-Current Loss in Iron and Copper. The resistance R_e corresponds to a dissipation factor D_e.

$$D_e = \frac{1}{Q_e} = \frac{\omega L}{R_e \text{ (parallel)}} = ef, \text{ where e is a constant.}$$

D_e is directly proportional to the frequency.

4.1.1.4.4 Hysteresis Loss. The hysteresis loss is proportional to the area enclosed by the hysteresis loop and to the rate at which this loop is traversed (frequency). It is a function of signal level and increases with frequency. Thus no simple frequency-independent resistor can be used in Figure 4-2 to represent this component (shown in dotted lines).

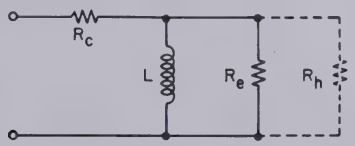


Figure 4-2. Equivalent circuit of an iron-cored coil at low frequencies.

The dissipation factor corresponding to this is

$$D_h = \frac{\omega L}{R_h \text{ (parallel)}} = h, \text{ where h is a constant.}$$

Thus D_h is independent of frequency.

4.1.1.4.5 Total Loss. The total dissipation factor (D) is the sum of the three separate dissipation factors.

$$D = \frac{1}{Q} = \frac{c}{f} + ef + h$$

where c, e, and h are constants related to the physical properties of the core. This function is plotted in Figure 4-3.

The minimum dissipation factor occurs at a frequency

$$f_{min} = \sqrt{c/e}$$

To separate the effects of these three components, a series of measurements can be made at several frequencies. When a curve of $D = \frac{1}{Q}$ for any coil has been found experimentally, numerical values for the three coefficients, c, h, and e, can be found by drawing 45° asymptotes to the curve. The intercepts of these lines with the 1-cycle axis are the values of c and e. The value of h is the difference between the observed minimum and twice the value of the two asymptotes at their crossing point.

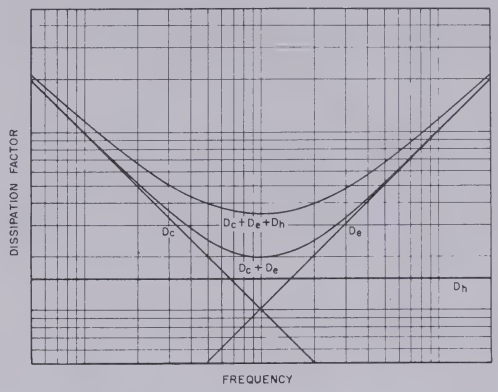


Figure 4-3. Curves showing relationships between dissipation factor and frequency. The three labeled straight lines are separate dissipation factor curves.

4.1.1.5 Inductance. The bridge measures series resistance and inductance (refer to paragraph 1.4). When the losses are primarily due to R_c, the simplified representation is valid. When the hysteresis and eddy-current losses are the most important, the measured values should be converted to parallel components. A chart is included inside the back cover of this book to facilitate this conversion.

The distributed capacitance of an inductor and of all the windings of a transformer is reflected to the winding under test and can affect the accuracy if measurements are made near the resonant frequency of the coil.

4.1.1.6 Summary. Since the permeability of core materials is very nonlinear, inductance measurements must be made under the same excitation conditions as the anticipated use. The specification of inductance must also include a statement of the dc and ac signal levels, the frequency, and any significant history of excitation.

If no history is given, the cyclic (SCM) condition is generally assumed. The Type 1633-A Incremental Inductance Bridge is designed for operation over the wide range of signal levels necessary for this type of measurement.

The bridge measures series components directly. If the parallel components are required, they can be calculated from the measured values. (See Figure 5-2.)

4.1.1.7 References. For a more detailed discussion of magnetic properties and their measurements, several excellent references are available:

1. "Iron-Cored Coils for Use at Audio Frequencies," a series of articles in the General Radio Experimenter, containing a detailed explanation of the behavior of iron-cored coils over wide frequency ranges. Included also is a discussion of the effect of the various physical parameters of a coil on the inductance and on the losses. The articles are

"Losses in Audio-Frequency Coils" L. B. Arguimbau
"How Good is an Iron-Cored Coil?" P. K. McElroy
"Those Iron-Cored Coils Again" Parts I and II, P. K. McElroy.

2. "Alternating-Current Measurements of Magnetic Properties," by H. W. Lamson[1].

This article contains a critical analysis of various procedures for determination of the permeability and core loss of ferromagnetic materials, together with a discussion of the limitations under which such observations are made and the interpretations which should be applied to the data obtained.

3. "Iron-Cored Inductors Carrying DC," General Radio Drafting Department Standards.

This article describes a design procedure for obtaining maximum inductance with a given dc current, as originally described by C. R. Hanna[2] and extended by P. K. McElroy.

[1] *Proc. I. R. E., February 1948.*
[2] *Journal A. I. E. E., February 1927.*

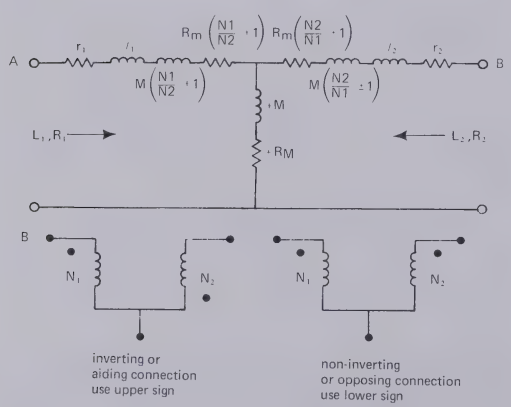


Figure 4-4. The equivalent circuit of a transformer at low frequencies.

4.1.2 TRANSFORMER MEASUREMENTS.

WARNING

Dangerously high voltages may be present at unused transformer terminals during measurements if the transformer has a high step-up ratio even though only low voltages are applied.

4.1.2.1 Equivalent Circuit. A useful low-frequency equivalent circuit of a two-winding transformer is shown in Figure 4-4. In this circuit

l_1 and l_2 are the leakage inductances of the two windings due to flux that cuts only one winding

$$l_1 = L_1 - \frac{N1}{N2} M$$

r_1 and r_2 the winding resistances are very nearly equal to the dc resistances at low frequency.
M the equivalent series mutual inductance.
Rm the equivalent series mutual resistance. due to core losses
N_1 and N_2 the number of turns on the two windings

The upper signs should be used for the inverting transformer connection (Figure 4.4) and the lower signs for the non-inverting connection.

The mutual impedance may be represented by a parallel inductance/resistance. The series and parallel values are related by the formulas of paragraph 1.4.

The equivalent circuit represents two windings connected together. If they are not, an ideal 1:1 transformer may be included to indicate this isolation.

This equivalent circuit does not indicate capacitance, neither lumped nor distributed. To a first order, this may be represented by lumped capacitance across the terminals. It may also be considered as just changing the effective values of the inductances and resistances shown.

Note that capacitance across the output terminals is transformed with respect to the input terminals so that the effective capacitance across winding 1 is

$$C_1 + \left(\frac{N2}{N1}\right)^2 C2 \text{ (approx). If } \frac{N2}{N1} \text{ is}$$

large, C_2 can greatly affect the measured value of L_1 and even make it appear negative (capacitive), even though the value of L_1 may be small.

4.1.3 INDUCTORS CARRYING DIRECT CURRENT. An air gap (g) is generally used in the core structure of an inductor carrying dc current. For a given coil and core, with a given value of direct current in the coil, there is an optimum size of the air gap that results in the maximum inductance of the coil, as indicated in Figure 4-5. A procedure for determination of the optimum design of such an inductor has been derived by C. R. Hanna (refer to paragraph 4.1.1.7). The empirical measurements required to design such coils can be made on the Type 1633-A Incremental Inductance Bridge. The inductance of the coil is measured with the desired ac voltage and dc bias current applied at the GENERATOR terminals.

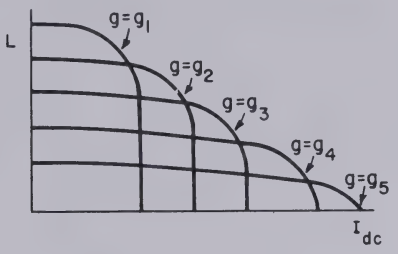


Figure 4-5. Use of optimum-size air gap in an inductor carrying a given value of direct current to produce maximum value of inductance of the coil.

4.2 AC RESISTANCE MEASUREMENTS.

4.2.1 GENERAL. Incremental ac resistance can be defined in a manner similar to incremental inductance. The value of resistance indicated by the bridge is the ratio of the fundamental component of voltage to the fundamental component of current.

In the following paragraphs are noted some of the reasons for the difference between the ac and dc resistances of a component.

4.2.1.1 Losses. Losses of other forms, such as core losses or reflected load losses, will cause the indicated series resistance of a coil to be higher than its dc resistance.

4.2.1.2 Skin and Proximity Effects. At higher frequencies, the magnetic field of a conductor (and of adjacent conductors) forces the current to be distributed nonuniformly throughout its cross section, thereby increasing its effective resistance. At high audio frequencies, these effects may be appreciable in coils, but they are negligible in most wire-wound resistors.

4.2.1.3 Lumped and Distributed Capacitances. The lumped and distributed capacitances across a resistor change its effective series resistance. These capacitances may be important with inductors and with resistors of values over several hundred ohms.

4.2.1.4 Nonlinearities. This term applies to any resistor whose value is a function of current or power. Thermistors, lamp bulbs, varistors, diodes, and many semiconductor elements are examples of this type.

4.2.2 SEMICONDUCTOR MEASUREMENTS. The incremental resistance of semiconductor circuit elements, such as the forward resistance of rectifiers or the dynamic resistance of Zener diodes, can be easily measured on the bridge over a wide range of dc bias currents. For these measurements, the ac-signal current is generally kept much smaller than the biasing direct current. Under these conditions, the bridge measures the slope of the volt-ampere characteristic at the bias point. The proper polarity of the bias source must be observed. The operating procedure is described in Section 2.

4.2.3 CAPACITIVE BALANCE. In the Type 1633-A Bridge, the L control provides a phase balance for inductive resistors. If the phase of the unknown resistor is capacitive, as it usually is with large-valued resistors, the L-control balance will appear to be below zero. An external capacitor (C_b) can be connected between the low unknown terminal and the GENERATOR ground terminal, to effect a capacitive balance. The L control can be used near zero for a fine phase balance. The value of the effective capacitance shunting the unknown resistor can be calculated from:

$$C_x \approx \frac{R_b}{R_x}\left[C_b - \frac{L_o}{R_b R_o}\right]$$

$$R_x \approx R_o + \omega^2 L_o R_b C_b$$

where L_o = inductance indicated on L control scale
R_o = resistance indicated on R control scale

Values of R_b are given in Table 1. Since the value of R_x depends upon the L control reading, the external capacitor C_b should be adjusted to give a balance with the L control near zero.

SECTION **5**

SPECIAL MEASUREMENTS

5.1 GENERAL.

A discussion of some of the more unusual measurements that can be made with the Type 1633-A is given in this section. They include:

Grounded Unknowns
Use at Higher Currents
Three Terminal Measurements
Use with Nonsinusoidal Waveforms
Remote Measurements
Measurement of Mutual Inductance
Limit Testing
Use at Other Frequencies
Displaying AC Hysteresis Loops

5.2 GROUNDED UNKNOWNS.

Since neither UNKNOWN terminal of the Type 1633-A Bridge is grounded, special arrangements are necessary to measure grounded unknowns. In many cases, the external circuit can be rearranged to permit operation of the bridge in a normal manner. If this cannot be done, either of the two procedures described below can be used, but proper safety precautions should be observed. In either case, the ground connection in the three-wire power cord must be disconnected.

5.2.1 GROUNDING HIGH UNKNOWN TERMINAL.

CAUTION: This method places the bridge panel and controls at the full generator voltage above ground and should not be used with high voltages.

With this connection, the capacitance of the case to ground is placed across the generator; no error is produced.

5.2.2 GROUNDING LOW UNKNOWN TERMINAL.

In this case the bridge panel and controls are at a potential above ground determined by

$E = IR_b$ (ac and/or dc)

(See Table 1 for values of R_b.)

This voltage can be as high as 180 volts. The capacitance C_b from the case to ground can cause an error. Refer to paragraph 2.4.3.8.

5.3 USE WITH HIGHER CURRENTS.

The bridge can be used on the a, b, or c range with ac and/or dc currents up to 70 amperes by the addition of an external 0.1-ohm, 500-watt resistor (R_m, Figure 5-1). Connections to any other generators must be removed. Use only the a, b, or c range and multiply

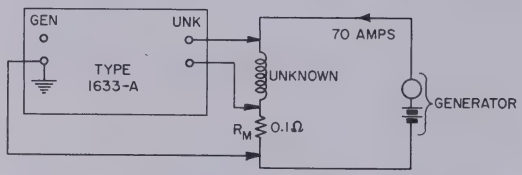


Figure 5-1. Circuit showing addition of 0.1-ohm resistor for measurements involving higher current values.

the L and R bridge readings by 0.1 (Q is direct reading). The maximum allowable rms generator voltage is indicated by the RANGE SELECTOR switch. The inductance L_m of the external resistor can cause an error. The following correction should be applied:

$$L_x = L_o + \left(\frac{R_o}{R_m}\right) L_m$$

$$R_x = R_o - \omega^2 \frac{L_m L_o}{R_m}$$

where L_o and R_o are the respective readings of the L and R dials.

An accessory unit, the General Radio Type 1633-P1 Range-Extension Unit, is available on special order. This unit contains a 250-watt, 0.1-ohm resistor, with the proper connections to extend the range of the bridge to 50 amperes (refer to paragraph 2.7).

5.4 THREE-TERMINAL MEASUREMENTS.

The bridge can be used to measure the transfer impedance of an inductive, three-terminal network, as in Figure 5-2. L_x and R_x (or Q) are measured directly. C_g causes no error. When C_b is large, it can cause a small error (refer to paragraph 2.4.3.8).

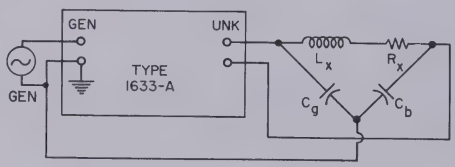


Figure 5-2. Diagram of connections for three-terminal measurements.

5.5 USE WITH NONSINUSOIDAL WAVEFORMS.

The Type 1633-A Bridge can be used with any generator of arbitrary waveform within the ratings of the bridge. The internal tuned detector can be used to measure the effective inductance at a harmonic of the generator signal, if desired. The SENSITIVITY control should be set only as high as needed to obtain a satisfactory balance. This avoids clipping on the other unbalanced components of the waveform (refer to paragraph 2.4.3.5).

It is often convenient to use as the generator the actual circuit in which the inductor is being used. The operation of the circuit will not be affected by the bridge to any appreciable extent, since the value of the resistance R_b, inserted in series with the unknown inductor, is usually much lower in impedance than the unknown. A typical power supply circuit and two possible methods for measurement of the filter choke under operating conditions are shown in Figure 5-3, a, b, and c.

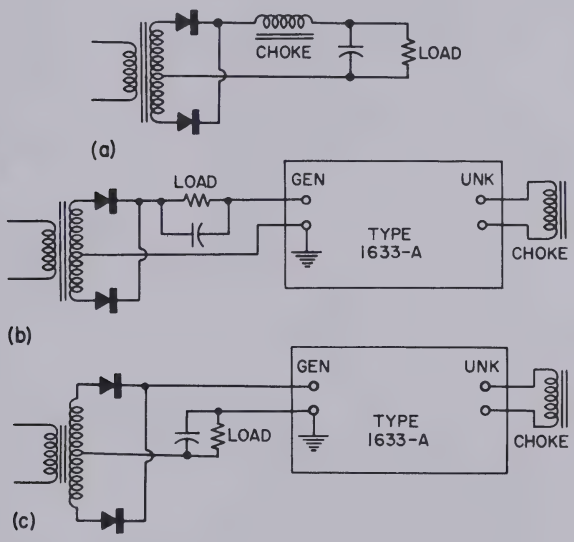


Figure 5-3. a, b, and c. A typical power supply circuit (a) and two possible methods for measurement of the filter choke (b and c).

5.6 REMOTE MEASUREMENTS.

Long leads to the unknown can cause measurement errors due to the resistance, inductance and capacitance of the leads. These can be minimized by using the proper leads and remaining errors can be corrected for.

When measuring low inductances, the leads should be heavy and twisted, to reduce their resistance and inductance. The lead resistance and inductance may be measured by shorting them together at the remote end (X in Figure 5-4), measuring the values, and subtracting them from the measured values of the unknown.

Capacitance between the leads, and capacitance from the lower lead to ground, cause errors in the measurement of large inductors. These can be minimized by shielding the upper lead, as in Figure 5-4 and connecting this shield to ground. Capacitance from the lower wire to ground can be measured and corrected for (see paragraph 2.4.3.8). If the lower lead is also shielded, this capacitance, C_b, can become quite large.

Under some conditions, noise pickup on long leads can cause difficulty in measurement. Magnetic pickup can be reduced by twisting the leads, and electrostatic pickup reduced by shielding the lower lead.

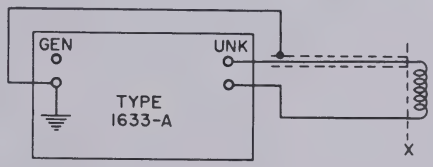


Figure 5-4. Use of a shielded cable to connect the unknown to the bridge.

5.7 MEASUREMENT OF MUTUAL INDUCTANCE

The mutual inductance between two coils may be accurately determined, if the core is linear, by measuring the two coils in series, first aiding and then opposing. The difference between these two inductance measurements is four times the mutual inductance between the coils. This is explained by the equivalent circuit of Figure 4-4.

In the aiding connection, the inductance from A to B is:

$$l_1 + l_2 + M\left(\frac{N1}{N2} + \frac{N2}{N1} + 2\right) = L_A$$

and opposing it is

$$l_1 + l_2 + M\left(\frac{N1}{N2} + \frac{N2}{N1} - 2\right) = L_B$$

$$L_A - L_B = 4M$$

If the core is non-linear, the value of M is a function of signal level and will be different in the two expressions unless the same ampere turns are applied for both measurements. Thus if E_A and I_A are used for the first measurement, and E_B and I_B are used for the second, it would be desirable to have

$$I_B = I_A\left(\frac{N1 + N2}{N1 - N2}\right)$$

or less exactly, $E_B = E_A\left(\frac{N1 - N2}{N1 + N2}\right)$

Note if N1=N2, I_B need not be infinite (nor E_B zero) because the value of L_B is independent of M and thus (quite) linear.

If the core is non-linear, it is usually useless to determine the mutual inductance accurately. Also most non-linear cores have high permeability so that the ratio of leakage inductance to total inductance is small. Therefore an approximate value of M may be made by measuring one coil and multiplying its measured inductance by $\frac{N2}{N1}$ where N1 is the number of turns of the coil measured and N2 the turns of the other coil. The actual value so obtained is (see Figure 4-4):

$$\frac{N2}{N1} L_1 = \frac{N2}{N1}\left(l_1 + \frac{N1}{N2} M\right) = M + \frac{N2}{N1} l_1 \cong M \left(1 + \frac{l_1}{L_1}\right)$$

Where L_1 is the measured inductance of the coil measured.

It is difficult to measure l_1 alone. The inductance of winding 1 with winding 2 short circuited is approximately

$$L_{ISC} = l_1 + \left(\frac{N1}{N2}\right)^2 l_2$$

usually $N_2 l_1$ is roughly equal to $N_1 l_2$, so that our approximate value of l_1 is one-half of this short-circuit inductance.

These measurements give the series value of mutual inductance. The parallel value may be calculated (see paragraph 1.4).

5.8 LIMIT TESTING.

The bridge can be set up to provide a "go no-go" indication that is very useful for component testing. With the panel meter used as the indicator, the procedure is as follows:

a. Connect one of the components to be measured (preferably one within limits) to the UNKNOWN terminals and balance the bridge.

b. Offset the L (or R) dial by the desired tolerance if the latter is symmetrical, or by half the allowable spread if the tolerance is unsymmetrical.

c. Adjust the SENSITIVITY control for a five-division meter deflection.

d. Set the L (or R) dial to the center value (the nominal value, if the tolerance is symmetrical).

e. The meter deflection will now be less than five divisions as each unknown component is connected to the bridge, if the component is within limits.

If the above method is used when the unknown has a tolerance greater than ±10%, the limits can be in error by more than 1%. To eliminate this error, set the L (or R) dial so that unknown components at both limits give the same meter deflection.

TABLE 3

FORMULAS FOR THE CALCULATION OF THE VALUE OF THE INTERNAL BRIDGE STANDARD.

DESIRED FREQUENCY	USE SWITCH POSITION	STANDARD RESISTANCE REQUIRED (OHMS)
20 - 200 Hz	50, 60, 100, 120 Hz	$1353 \frac{100}{\text{Hz}}$
200 - 2000 Hz	400 Hz, 800 Hz, 1 kHz	$1353 \frac{1\text{ kHz}}{f_{\text{kHz}}}$
2 - 20 kHz	10 kHz, 15.75 kHz	$1353 \frac{10\text{ kHz}}{f_{\text{kHz}}}$

5.9 USE AT OTHER FREQUENCIES.

The bridge can be made direct reading in Q and its internal null detector can be tuned to any frequency between 20 Hz and 20 kHz if the values of five resistors are changed as follows:

One of the internal bridge standards, R_{18} to R_{24}, must be replaced by a new standard resistor whose value can be calculated from the data in Table 3. Mount the new resistor between the first and second sections of the FREQUENCY switch in place of the resistor supplied with the bridge. Its tolerance should be consistent with the required Q accuracy. The new frequency must be in the same range as the frequency for which the resistors are replaced (see Table 3).

Four resistors are used to determine the detector frequency. They are located inside the shield can, on the rear of the FREQUENCY switch. The nominal value of these resistors can be calculated from the following relation:

$$R = 7960 \left(\frac{1\text{ kHz}}{f\text{ kHz}}\right) \text{ ohms.}$$

To give a somewhat flatter response, resistors R453 to R469 are approximately 1% lower than the nominal values and resistors R435 to R451 are approximately 1% higher. The components should have a tolerance of ±1%.

5.10 DISPLAYING AC HYSTERESIS LOOPS.

The ac hysteresis loop of an iron core can be displayed by means of a resistor, a capacitor, and a differential oscilloscope while the inductance of the coil is being measured on the bridge. The connections are shown in Figure 5-5. The impedance of the resistor should be high compared with that of the unknown; the impedance of the capacitor should be comparable to that of the unknown at the frequency of measurement. If a secondary winding is available on the coil under test, the voltage across the secondary should be used (dotted lines in the figure) instead of the voltage across the UNKNOWN terminals.

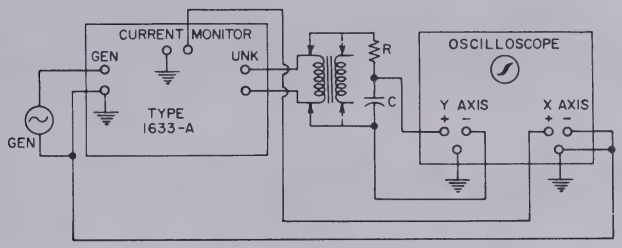


Figure 5-5. Method of displaying an ac hysteresis loop on an oscilloscope.

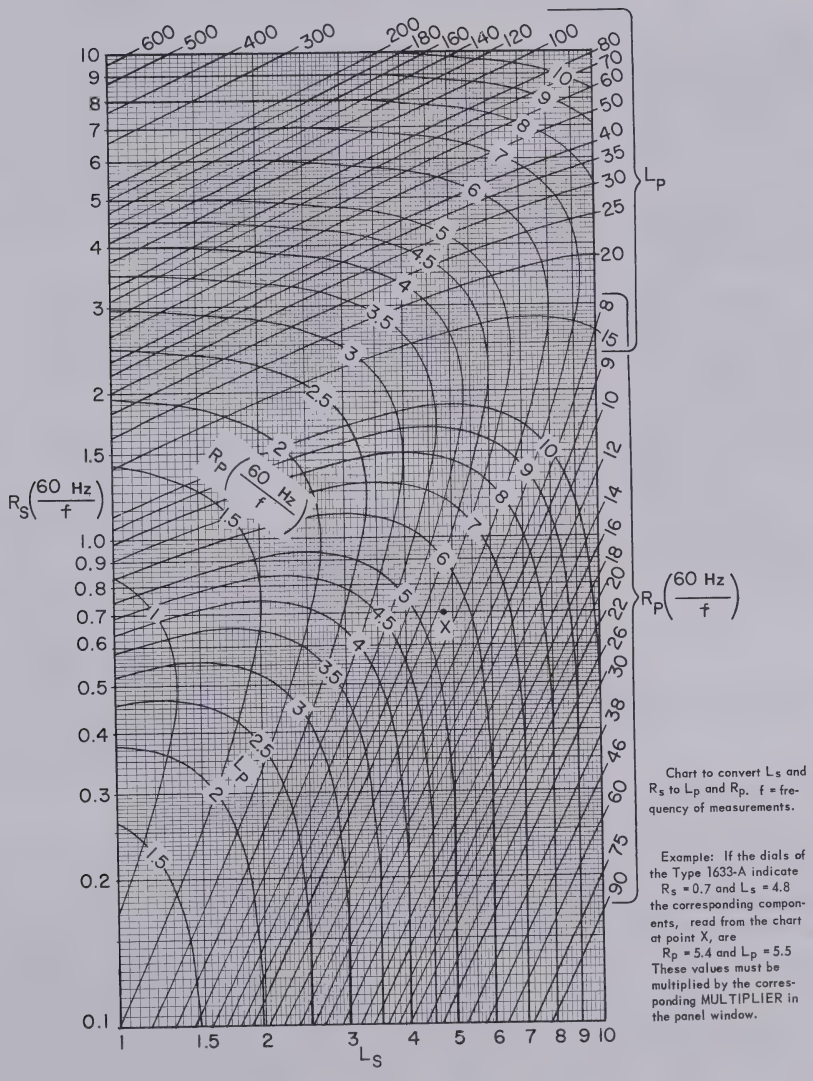


Chart to convert L_s and R_s to L_p and R_p. f = frequency of measurements.

Example: If the dials of the Type 1633-A indicate $R_s = 0.7$ and $L_s = 4.8$ the corresponding components, read from the chart at point X, are $R_p = 5.4$ and $L_p = 5.5$ These values must be multiplied by the corresponding MULTIPLIER in the panel window.

Figure 5-6.

SECTION **6**

TYPE 1630–AV INDUCTANCE MEASURING ASSEMBLY

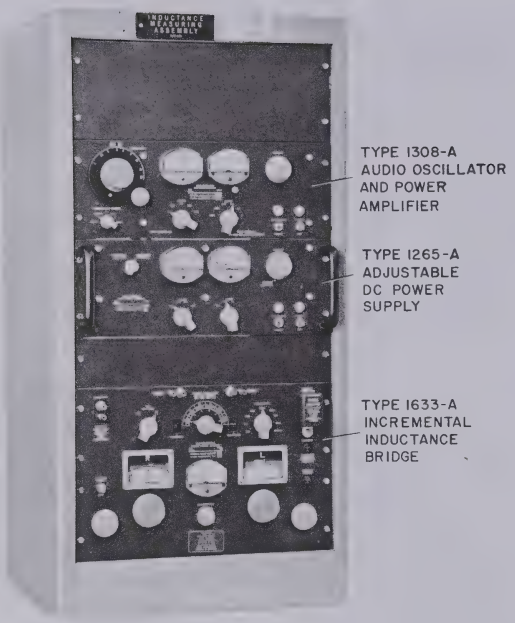


Figure 6-1. Type 1630-AV Inductance Measuring Assembly.

6.1 OPERATING PROCEDURE.

The operating procedure for the Type 1630-AV Inductance Measuring Assembly is covered in Section 2.

6.2 ALTERNATING CURRENT IN THE DC SUPPLY.

The value of the capacitor in the output of the Type 1265-A Adjustable DC Power Supply is a function of the settings of the range switches and is large enough to carry alternating current up to the amounts shown in Table 4. These figures apply for continuous operation at a room temperature of 70 F. They can be increased 25% for intermittent operation and should be reduced 1% per degree F for operation above 70 F. Note that all the capacitors are capable of carrying an alternating current greater than that indicated by the setting of the AMPS switch; on many ranges the corresponding capacitor can carry considerably more current.

Always use the lowest dc voltage range that gives the desired dc current, to permit the greatest ac current-carrying capacity.

When no direct current is used, the OUTPUT control of the Type 1265-A should be set to the OUTPUT SHORTED position. The instrument can then safely carry an alternating current of 5 amperes on any of the range switch positions.

6.3 MAXIMUM DIRECT CURRENT IN THE AC SUPPLIES.

The maximum value of direct current that can flow through the output of the Type 1308-A is determined by the flux-density limit of the output and current transformers. The value of this direct current for each range switch setting is given in Table 5. This maximum allowable current is always at least equal to the rating of the MAX AMPS AC switch position and, in many cases, it is much greater. The resulting error in the reading of the ac ammeter is negligible. The output from the dc supply should be increased slowly, as a sudden increase can trigger the overload circuits of the ac supply.

6.4 METER READINGS.

In the Type 1630 Inductance Measuring Assemblies, the power supplies are connected in series. Therefore the current through each generator is equal to the current in the loop. With the Type 1265-A, the dc ammeter is not affected by the alternating current. However, the ac ammeter of the Type 1308-A may be affected by a direct current larger than that indicated by Table 5.

The indication of the ac ammeter is proportional to the average value of the alternating current.

TABLE 4

CAPACITANCE AND CURRENT VS RANGE SWITCH SETTINGS FOR THE TYPE 1265-A ADJUSTABLE DC POWER SUPPLY.

AMPS SWITCH SETTING		VOLTS SWITCH SETTING 12.5	40	125	400
5	Output Capacitor	8100 μf	8100 μf		
	Maximum Current 60-Hz	5.6 amp	5.6 amp		
	Allowable Current 120-Hz	7.0	7.0		
	Allowable Current 400-Hz and above	9.8	9.8		
1.6	Output Capacitor	8100 μf	3100 μf	1100 μf	
	Maximum Current 60-Hz	5.6 amp	3.6 amp	2.2 amp	
	Allowable Current 120-Hz	7.0	4.5	3.2	
	Allowable Current 400-Hz and above	9.8	6.3	4.5	
0.5	Output Capacitor	3100 μf	1100 μf	320 μf	80 μf
	Maximum Current 60-Hz	3.6 amp	2.2 amp	2.2 amp	1.1 amp
	Allowable Current 120-Hz	4.5	3.2	3.1	1.5
	Allowable Current 400-Hz and above	6.3	4.5	4.4	2.2
0.16	Output Capacitor	1100 μf	320 μf	80 μf	50 μf
	Maximum Current 60-Hz	2.2 amp	2.2 amp	1.1 amp	0.75 amp
	Allowable Current 120-Hz	3.2	3.1	1.5	1.1
	Allowable Current 400-Hz and above	4.5	4.4	2.2	1.5

TABLE 5

MAXIMUM ALLOWABLE DC IN TYPE 1308-A AUDIO OSCILLATOR AND POWER AMPLIFIER.

MAX VOLTS AC SWITCH SETTING	MAX AMPS AC SWITCH SETTING 5.0	1.6	0.5	0.16	.05	.016
400			0.5	0.5	.16	.16
125		1.6	1.6	1.6	.16	.16
40	5.0	1.6	1.6	1.6	.16	.16
12.5	5.0	1.6	1.6	1.6	.16	.16
4.0	5.0	1.6	1.6	1.6	.16	.16

TABLE 6
APPROXIMATE INDUCTANCE REQUIRED TO PRODUCE SERIES RESONANCE.

TYPE 1265-A OUTPUT CAPACITOR	FREQUENCY SWITCH SETTING (TYPE 1633-A) (Hz)								
	50	60	100	120	400	800	1 k	10 k	15.75 k
8100 μf	1.3	870	310	220	20	4.9	3.1	0.031	0.013
3100 μf	3.3	2.3	820	570	51	13	8.2	0.082	0.033
1100 μf	9.2	6.4	2.3	1600	150	36	23	0.23	0.093
320 μf	32	22	8.0	5.5	500	125	80	0.8	0.32
80 μf	130	120	32	22	2.0	500	320	3.2	1.3
50 μf	200	140	51	35	3.2	800	510	5.1	2.0
					mh		μh		

Each panel voltmeter indicates the voltage across its own power supply. This voltage differs from that across the Type 1633-A Bridge by the voltage drop in the other supply. The ac voltage drop in the dc supply is usually small; it can easily be calculated from the value of the capacitance, given in Table 4, and the alternating current. This ac voltage drop should be subtracted vectorially from the voltmeter reading, to obtain the true bridge voltage.

The voltage across the unknown differs from the voltage applied to the bridge by the amount of the voltage drop in the current-sampling resistor, R_b (see Figure 3-4). This voltage drop (IR_b) is easily calculated (see Table 1). It should be noted that the bridge voltage is the vector sum of the voltage drops in the unknown inductor and in resistor R_b.

6.5 POSSIBLE RESONANCE OF DC SUPPLY CAPACITOR WITH INDUCTOR UNDER TEST.

It is possible for the output capacitor of the Type 1265-A to resonate with the inductor under test, thus causing considerable increase in the alternating current. In practice, this resonance condition is rarely encountered, particularly if the lowest dc output voltage range that gives the required direct current is used.

Table 6 gives the inductance required for resonance as a function of the frequency and the capacitance. These are approximate values, due to the wide positive tolerances of the capacitors.

When resonance occurs, the voltmeter on the ac supply may read considerably less than the actual voltage on the unknown inductor. An additional voltmeter, connected across the GENERATOR terminals, can be used to measure the actual voltage.

This resonance effect is important only when the Q of the unknown is near or greater than unity. An inductive resistor, whose inductance may be low enough to produce resonance, will, however, have too low a value of Q to produce a noticeable voltage increase.

SECTION 7

SERVICE AND MAINTENANCE

7.1 GR FIELD SERVICE.

Our warranty (at the front of this manual) attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone the nearest GR service facility (see back page), giving full information of the trouble and of steps taken to remedy it. Describe the instrument by type, serial, and ID numbers. (Refer to front and rear panels.)

Instrument Return. Before returning an instrument to General Radio for service, please ask our nearest office for a "Returned Material" number. Use of this number in correspondence and on a tag tied to the instrument will ensure proper handling and identification. After the initial warranty period, please avoid unnecessary delay by indicating how payment will be made, i.e., send a purchase-order number or (for transportation charges) request "C.O.D."

For return shipment, please use packaging that is adequate to protect the instrument from damage, i.e., equivalent to the original packaging. Advice may be obtained from any GR office.

7.2 NOISY OR ERRATIC BALANCES.

When the Type 1633-A Incremental Inductance Bridge has been idle for an extended period, surface contamination of the wire-wound L or R-Q potentiometer may cause erratic behavior of the null indicator. To remedy this situation, rotate the controls back and forth several times.

7.3 BRIDGE ERROR AT LOW FREQUENCIES.

To locate a defective component, first determine which particular range or ranges are affected. The standards involved in each range are listed in Table 7.

7.4 BRIDGE WILL NOT BALANCE.

If no balance can be obtained, one or more of the internal amplifiers may not be functioning. A check of the following points should help to locate the difficulty. All voltages are dc, with reference to ground.

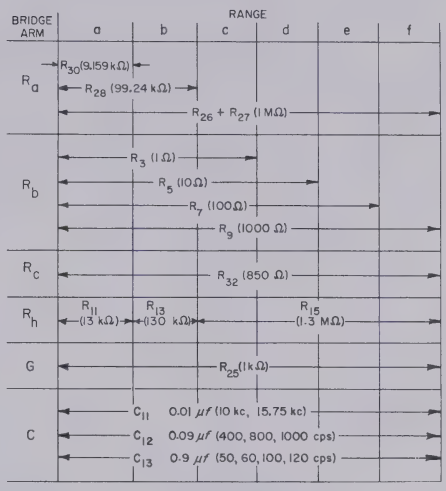
a. Power Supply. Voltage at terminal 43 (Figure 7-1) approx +30 volts.

(1) No voltage —— check fuses.

(2) Voltage too high —— check regulator transistor Q501 or Q502, located behind rear panel.

TABLE 7

BRIDGE STANDARDS IN USE FOR EACH SETTING OF THE RANGE SELECTOR SWITCH.



b. Isolating Amplifiers. Voltage at terminal 70 (Figure 7-1) approx +18 volts on each amplifier board.

c. Operational Amplifier. Voltage at the case of capacitor C307 (Figure 7-1) approx +12 volts.

d. Detector.

(1) Test voltages (Figure 7-2):

At terminal 66 -- approximately +6 volts.

At terminal 68 -- approximately +22 volts.

(2) Noisy Detector:

The detector noise should be less than one meter division at 1 kc with the SENSITIVITY control fully clockwise. Excessive noise may be caused by transistor Q201 or Q301 (Figure 7-1), or Q400. These are located in sockets on the various amplifier circuit boards. To change Q400, take off the dress panel by removing panel knobs and screws. Transistor Q400 is located under the shield on which the SENSITIVITY control is mounted.

7.5 SAFETY COVER WILL NOT UNLOCK.

The safety cover may become misaligned (due to improper operation of the instrument) making it impossible to release the cover lock. When this occurs, remove the instrument from the cabinet and release the lock from behind the panel.

7.6 CALIBRATION PROCEDURE.

7.6.1 GENERAL. The calibration of the bridge depends primarily on passive standards and is not affected by changes in transistors or in operating conditions normally encountered in a laboratory. If, however, it is necessary to check or adjust the calibration, the procedure noted in the following paragraphs should be used.

7.6.2 STANDARDS. The following standards are required to check the calibrations of the bridge.

Resistors:

one, each of the following values: 1, 10, 50, 100, 160, 200, 500, 700, 1000, 10,000 and 100,000 ohms. The General Radio Type 1434-X Decade Resistor is recommended.

1/2-watt, composition-carbon resistors, of the following values, ±5%: 11, 56, 110, and 1100 ohms.

Air-core Inductors:

1 mh, GR Type 1482-E

10 mh, GR Type 1482-H or GR 1491-D Decade Inductor

100 mh, GR Type 1482-L

7.6.3 R-RANGE MULTIPLIERS. To check the bridge arms, measure the following standard resistors at 1 kc:

RANGE	STANDARD (OHMS)
a	1
b	10
c	100
d	1000
e	10,000
f	100,000

The General Radio Type 1434-X Decade Resistor is suitable. The lead resistance should be added to the values of the standards on the low-resistance ranges.

7.6.4 L-RANGE MULTIPLIERS. Measure a 10-mh, air-core inductor (General Radio Type 1482-H) on the following ranges, to check the standard capacitors:

RANGE	FREQUENCY
b	100 cps
c	1 kc
d	10 kc

7.6.5 Q-RANGE RESISTORS. Measure a standard air-core inductor at each engraved frequency, using first the R and then the Q scales. The readings should correspond.

$$Q = \frac{2\pi fL}{R}$$

7.6.6 SCALE CALIBRATIONS. Measure the standards listed below, at 1 kc on the c range, to check the calibration of the R-Q and L potentiometers. To make small changes, remove the dress panel and adjust the screws surrounding the shafts.

R STANDARD	L STANDARD
10 ohms	1 mh
50 ohms	5 mh
100 ohms	10 mh
160 ohms	20 mh
200 ohms	50 mh
500 ohms	100 mh
700 ohms	
1000 ohms	

7.7 METER WINDOW CARE

The clear acrylic meter window can become susceptible to electrostatic-charge buildup and can be scratched, if improperly cleaned.

It is treated inside and out in manufacturing with a special non-abrasive anti-static solution. Statnul , which normally should preclude any interference in meter operation caused by electrostatic effects. The problem is evidenced by the inability of the meter movement to return promptly to a zero reading, once it is deenergized. As supplied by General Radio, the meter should return to zero reading within 30 seconds, immediately following the placement of a static charge, as by rubbing the outside surface. This meets the requirements of ANSI standard C39.1-1972.

If static-charge problems occur, possibly as the result of frequent cleaning, the window should be carefully polished with a soft dry cloth, such as cheesecloth or nylon chiffon. Then, a coating of Stanul should be applied with the polishing cloth.

CAUTION

Do not use any kind of solvent. Kleenex or paper towels can scratch the window surface.

If it should be necessary to place limit marks on the meter window, paper-based masking tape is recommended, rather than any kind of marking pen, which could be abrasive or react chemically with the acrylic.

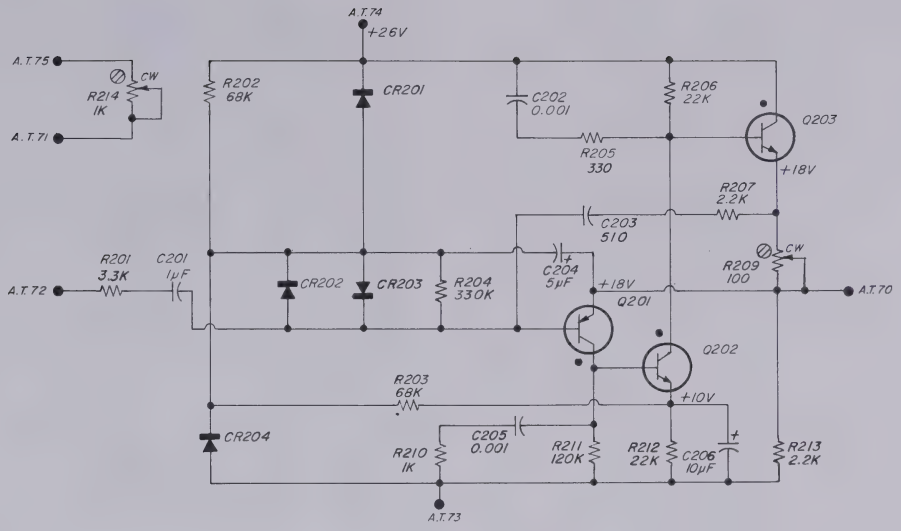


Figure 7-3. Schematic diagram of isolating amplifier.

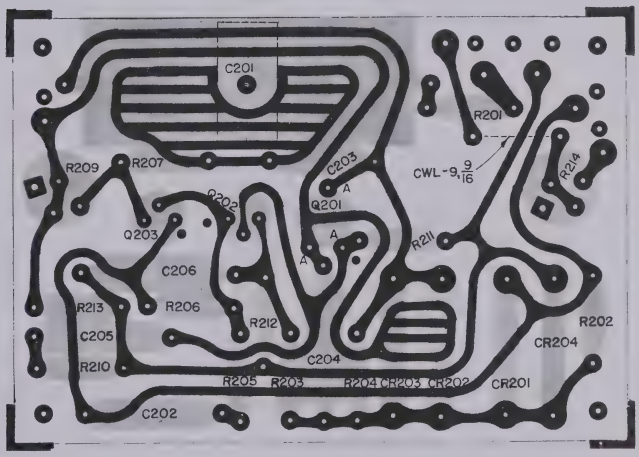


Figure 7-4. Etched-board layout of isolating amplifier.

NOTE: The number on the foil side is not the part number for the complete assembly. The dot on the foil at the transistor socket indicates the collector lead.

7.6 CALIBRATION PROCEDURE.

7.6.1 GENERAL. The calibration of the bridge depends primarily on passive standards and is not affected by changes in transistors or in operating conditions normally encountered in a laboratory. If, however, it is necessary to check or adjust the calibration, the procedure noted in the following paragraphs should be used.

7.6.2 STANDARDS. The following standards are required to check the calibrations of the bridge.

Resistors:

one, each of the following values: 1, 10, 50, 100, 160, 200, 500, 700, 1000, 10,000 and 100,000 ohms. The General Radio Type 1434-X Decade Resistor is recommended.

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1 mh, GR Type 1482-E

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100 mh, GR Type 1482-L

7.6.3 R-RANGE MULTIPLIERS. To check the bridge arms, measure the following standard resistors at 1 kc:

RANGE	STANDARD (OHMS)
a	1
b	10
c	100
d	1000
e	10,000
f	100,000

The General Radio Type 1434-X Decade Resistor is suitable. The lead resistance should be added to the values of the standards on the low-resistance ranges.

7.6.4 L-RANGE MULTIPLIERS. Measure a 10-mh, air-core inductor (General Radio Type 1482-H) on the following ranges, to check the standard capacitors:

RANGE	FREQUENCY
b	100 cps
c	1 kc
d	10 kc

7.6.5 Q-RANGE RESISTORS. Measure a standard air-core inductor at each engraved frequency, using first the R and then the Q scales. The readings should correspond.

$$Q = \frac{2\pi fL}{R}$$

7.6.6 SCALE CALIBRATIONS. Measure the standards listed below, at 1 kc on the c range, to check the calibration of the R-Q and L potentiometers. To make small changes, remove the dress panel and adjust the screws surrounding the shafts.

R STANDARD	L STANDARD
10 ohms	1 mh
50 ohms	5 mh
100 ohms	10 mh
160 ohms	20 mh
200 ohms	50 mh
500 ohms	100 mh
700 ohms	
1000 ohms	

7.7 METER WINDOW CARE

The clear acrylic meter window can become susceptible to electrostatic-charge buildup and can be scratched, if improperly cleaned.

It is treated inside and out in manufacturing with a special non-abrasive anti-static solution. Statnul , which normally should preclude any interference in meter operation caused by electrostatic effects. The problem is evidenced by the inability of the meter movement to return promptly to a zero reading, once it is deenergized. As supplied by General Radio, the meter should return to zero reading within 30 seconds, immediately following the placement of a static charge, as by rubbing the outside surface. This meets the requirements of ANSI standard C39.1-1972.

If static-charge problems occur, possibly as the result of frequent cleaning, the window should be carefully polished with a soft dry cloth, such as cheesecloth or nylon chiffon. Then, a coating of Stanul should be applied with the polishing cloth.

CAUTION

Do not use any kind of solvent. Kleenex or paper towels can scratch the window surface.

If it should be necessary to place limit marks on the meter window, paper-based masking tape is recommended, rather than any kind of marking pen, which could be abrasive or react chemically with the acrylic.

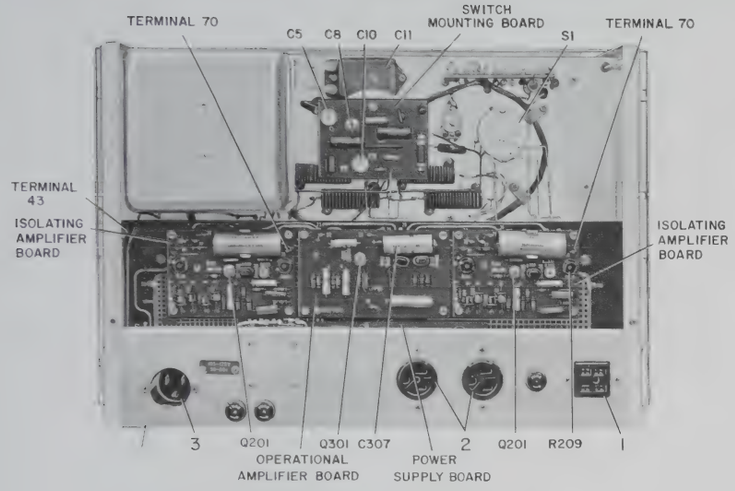


Figure 7-1. Rear interior view.

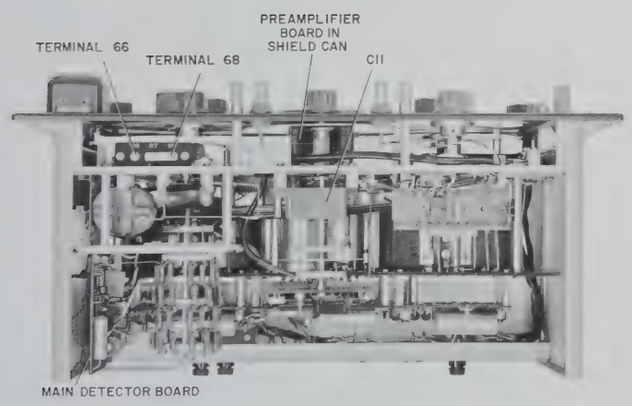


Figure 7-2. Top interior view.

ELECTRICAL PARTS LIST

ISOLATING AMPLIFIER PC BOARD P/N 1633-2720

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 201	CAP MYLAR 1.0UF 10 PCT 400V	4860-7918	56289	410P 1 UF 10PCT
C 202	CAP MICA 1000PF 10PCT 500V	4660-6400	81349	CM20FD102K
C 203	CAP MICA 510PF 10PCT 500V	4620-1510	81349	CM15FD511K
C 204	CAP ALUM 5 UF 50V	4450-3900	56289	30D505G050
C 205	CAP MICA 1000PF 10PCT 500V	4660-6400	81349	CM20FD102K
C 206	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
CR 201	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 202	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 203	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 204	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
Q 202	TRANSISTOR 2N3414	8210-1290	56289	2N3414
Q 203	TRANSISTOR 2N1304	8210-1304	01295	2N1304
R 201	RES COMP 3.3 K 5PCT 1/2W	6100-2335	81349	RCR20G332J
R 202	RES COMP 68 K 5PCT 1/2W	6100-3685	81349	RCR20G683J
R 203	RES COMP 68 K 5PCT 1/2W	6100-3685	81349	RCR20G683J
R 204	RES COMP 330 K 5PCT 1/2W	6100-4335	81349	RCR20G334J
R 205	RES COMP 330 OHM 5PCT 1/2W	6100-1335	81349	RCR20G331J
R 206	RES COMP 22 K 5PCT 1/2W	6100-3225	81349	RCR20G223J
R 207	RES COMP 2.2 K 5PCT 1/2W	6100-2225	81349	RCR20G222J
R 209	POT COMP TRM 100 OHM 20PCT 1T	6040-0100	01121	YR101M
R 210	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 211	RES COMP 120 K 5PCT 1/2W	6100-4125	81349	RCR20G124J
R 212	RES COMP 22 K 5PCT 1/2W	6100-3225	81349	RCR20G223J
R 213	RES COMP 2.2 K 5PCT 1/2W	6100-2225	81349	RCR20G222J
R 214	POT COMP TRM 1K OHM 20PCT 1T	6040-0400	01121	YR102M

MECHANICAL PARTS LIST

Fig Ref.	Qty	Description	GenRad Part No.	Fed Mfg Code	Mfg Part No.
FRONT					
1	1	Shield Asm (Not Shown)	1633-1130	24655	1633-1130
2	1	Knob Q-R Selector	5500-5421	24655	5500-5421
	1	Bushing	4143-3161	24655	4143-3161
4	1	Knob Range Selector	5500-5421	24655	5500-5421
	1	Bushing	4143-3161	24655	4143-3161
6	1	Knob Frequency	5500-5421	24655	5500-5421
	1	Bushing	4143-3161	24655	4143-3161
7	1	Shield Asm	1633-1110	24655	1633-1110
8	1	Knob L; Vernier	5520-5420	24655	5520-5420
	1	Bushing	4143-5161	24655	4143-5161
9	1	Knob L	5520-5520	24655	5520-5520
	1	Bushing Assembly	1633-1500	24655	1633-1500
	1	Washer	8150-0200	24655	8150-0200
	1	Spacer	7590-1650	24655	7590-1650
10	1	Knob Sensitivity	5520-5421	24655	5520-5421
	1	Bushing	4143-3161	24655	4143-3161
11	1	Knob R-Q	5520-5520	24655	5520-5520
	1	Bushing Assembly	1633-1500	24655	1633-1500
	1	Washer	8150-0200	24655	8150-0200
	1	Spacer	7590-1650	24655	7590-1650
12	1	Knob Q, Vernier	5520-5420	24655	5520-5420
	1	Bushing	4143-5161	24655	4143-5161
ITEMS NOT SHOWN OR WITHOUT CALLOUT NUMBERS					
	1	Window R-Q	1633-7000	24655	1633-7000
	1	Window L	1633-7002	24655	1633-7002
	8	Panel Screws	7270-6210	24655	7270-6210
	1	Right End Frame Asm	5310-7080	24655	5310-7080
	1	Left End Frame Asm	5310-7081	24655	5310-7081
	4	Foot, Soft	5260-0710	24655	5260-0710
	2	Lens, Red	5620-0200	72610	101-971
REAR					
	3	Fuse Extractor Post BK	5650-0100	75915	342-004
	1	Input Plate	5590-1664	24655	5590-1664

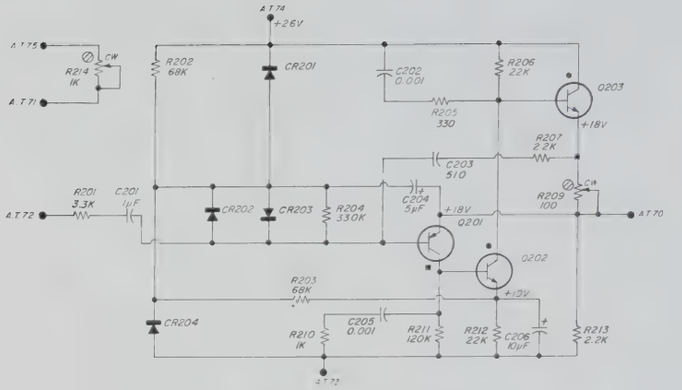


Figure 7-3. Schematic diagram of isolating amplifier.

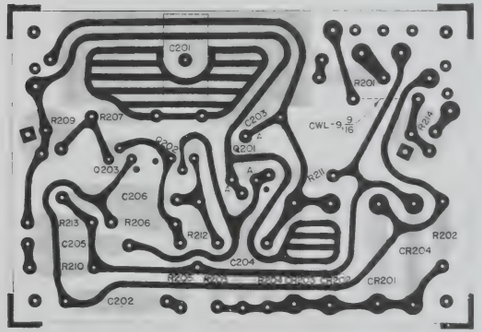


Figure 7-4. Etched-board layout of isolating amplifier.

NOTE: The number on the foil side is not the part number for the complete assembly. The dot on the foil at the transistor socket indicates the collector lead.

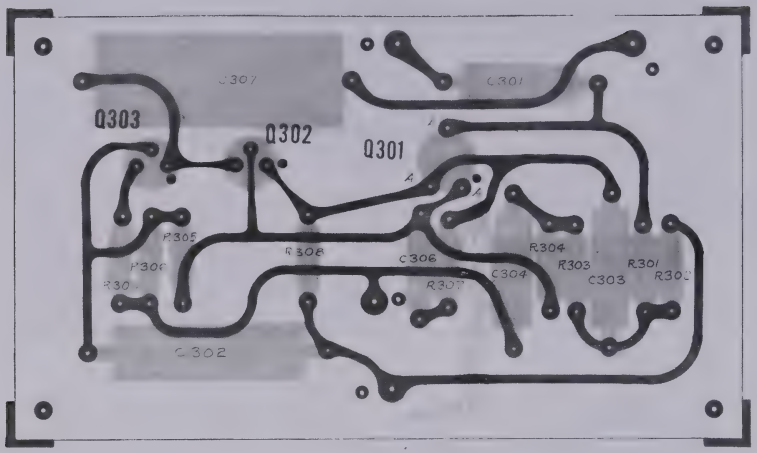


Figure 7-6. Etched-board layout of operational amplifier.

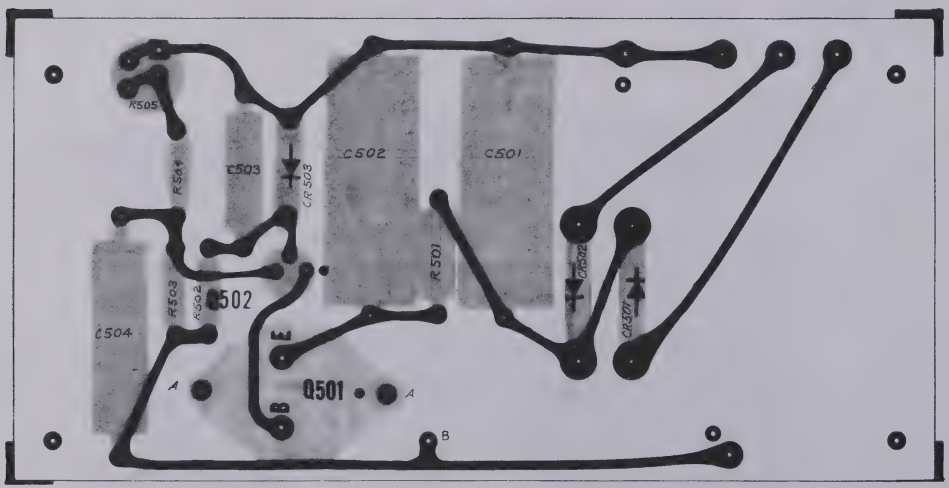
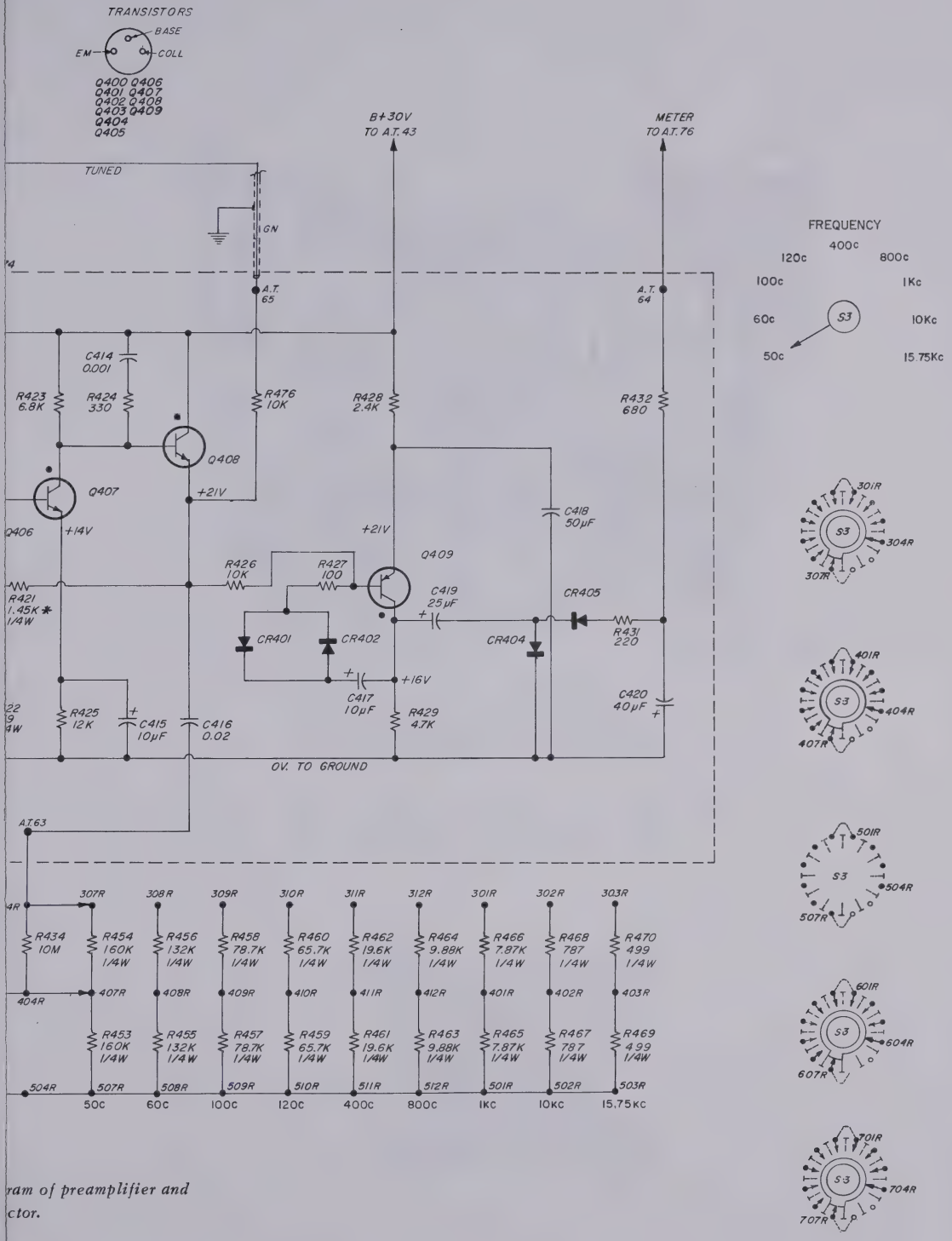


Figure 7-8. Etched-board layout of power supply.



ram of preamplifier and
ctor.

ELECTRICAL PARTS LIST

OPERATIONAL AMPLIFIER PC BOARD P/N 1633-2710

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 301	CAP ALUM 5 UF 50V	4450-3900	56289	30D505G050
C 302	CAP ALUM 25 UF 50V	4450-3000	56289	30D256G050
C 303	CAP ALUM 5 UF 50V	4450-3900	56289	30D505G050
C 304	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 306	CAP MICA 68 PF 5PCT 500V	4700-0371	81349	CM05ED680JN
C 307	CAP ALUM 200 UF 12V	4450-0400	56289	30D207G012
Q 302	TRANSISTOR 2N3414	8210-1290	56289	2N3414
Q 303	TRANSISTOR 2N3414	8210-1290	56289	2N3414
R 301	RES COMP 220 K 5PCT 1/2W	6100-4225	81349	RCR20G224J
R 302	RES COMP 100 K 5PCT 1/2W	6100-4105	81349	RCR20G104J
R 303	RES COMP 100 K 5PCT 1/2W	6100-4105	81349	RCR20G104J
R 304	RES COMP 100 K 5PCT 1/2W	6100-4105	81349	RCR20G104J
R 305	RES COMP 82 K 5PCT 1/2W	6100-3825	81349	RCR20G823J
R 306	RES COMP 68 K 5PCT 1/2W	6100-3685	81349	RCR20G683J
R 307	RES COMP 750 OHM 5PCT 1/2W	6100-1755	81349	RCR20G751J
R 308	RES CR 1.124K OHM .25 PCT 1/8W	6981-4011	24655	6981-4011
R 309	RES COMP 1.2 K 5PCT 1/2W	6100-2125	81349	RCR20G122J

POWER SUPPLY PC BOARD P/N 1633-2730

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 501	CAP ALUM 50 UF 50V	4450-2200	56289	30D506G050
C 502	CAP ALUM 50 UF 50V	4450-2200	56289	30D506G050
C 503	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 504	CAP ALUM 60 UF 25V	4450-2900	56289	30D606G025
CR 501	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 502	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 503	ZENER 1N5678 18V 5PCT .4W	6083-1016	14433	IN5678
Q 501	TRANSISTOR 2N176	8210-1760	04713	2N176
Q 502	TRANSISTOR 2N1304	8210-1304	01295	2N1304
R 501	RES COMP 100 OHM 5PCT 1W	6110-1105	81349	RCR32G101J
R 502	RES COMP 1.5 K 5PCT 1/2W	6100-2155	81349	RCR20G152J
R 503	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 504	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 505	POT COMP TRM 1K OHM 20PCT 1T	6040-0400	01121	YR102M

NOTE

Electrical parts information in this section is presented in such a way that all the data for a part-numbered sub-assembly are visible in a single opening of the manual. Thus, the parts list appears on left-hand pages, while the part-location diagram (on the apron) and the schematic diagram (tip out) are on right-hand pages.

REFERENCE DESIGNATOR ABBREVIATIONS

B	= Motor	P	= Plug
BT	= Battery	Q	= Transistor
C	= Capacitor	R	= Resistor
CR	= Diode	S	= Switch
DS	= Lamp	T	= Transformer
F	= Fuse	U	= Integrated Circuit
J	= Jack	VR	= Diode, Zener
K	= Relay	X	= Socket for Plug-In
KL	= Relay Coil	Y	= Crystal
KS	= Relay Switch	Z	= Network
L	= Inductor		
M	= Meter	References	
MK	= Microphone	ASA Y32.16 and MIL-STD-16C	

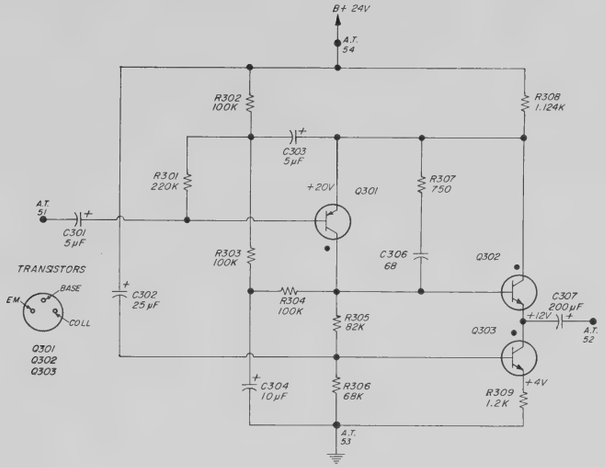


Figure 7-5. Schematic diagram of operational amplifier.

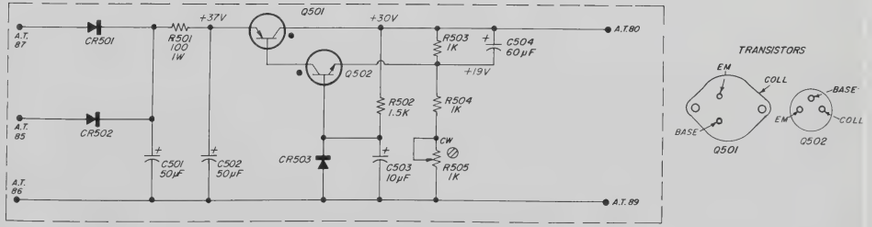


Figure 7-7. Schematic diagram of power supply.

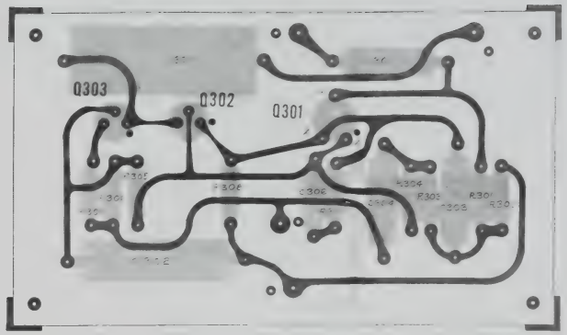


Figure 7-6. Etched-board layout of operational amplifier.

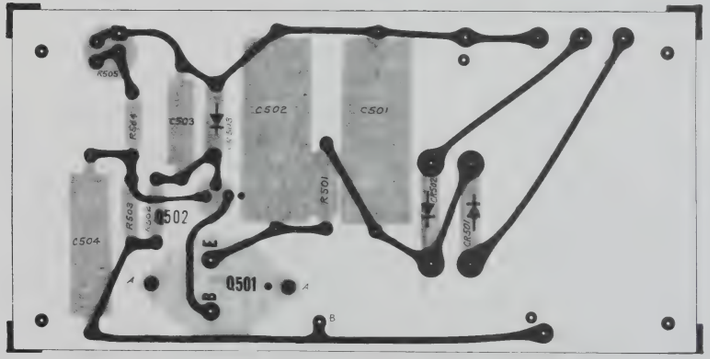


Figure 7-8. Etched-board layout of power supply.

ELECTRICAL PARTS LIST

MAIN DETECTOR PC BOARD P/N 1633-2740

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 405	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 406	CAP TANT 68 UF 20PCT 15V	4450-5615	56289	150D686X0015R2
C 407	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 408	CAP MICA 20000PF 1PCT 300V	4560-0400	81349	CM07F203F
C 409	CAP MICA 1000 PF 5PCT 500V	4700-1190	81349	CM06FD102JN
C 410	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 411	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 412	CAP MICA 20000PF 1PCT 300V	4560-0400	81349	CM07F203F
C 413	CAP MICA 20000PF 1PCT 300V	4560-0400	81349	CM07F203F
C 414	CAP MICA 1000 PF 5PCT 500V	4700-1190	81349	CM06FD102JN
C 415	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 416	CAP MICA 20000PF 1PCT 300V	4560-0400	81349	CM07F203F
C 417	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 418	CAP ALUM 50 UF 50V	4450-2200	56289	30D506G050
C 419	CAP ALUM 25 UF 50V	4450-3000	56289	30D256G050
C 420	CAP ALUM 40 UF 6V	4450-3600	56289	30D406G006
CR 401	DIODE RECTIFIER 1N645	6082-1016	14433	1N645
CR 402	DIODE RECTIFIER 1N645	6082-1016	14433	1N645
CR 404	DIODE 1N191 90PIV IR 125UA GE	6082-1008	14433	1N191
CR 405	DIODE 1N191 90PIV IR 125UA GE	6082-1008	14433	1N191
Q 402	TRANSISTOR 2N1305	8210-1305	01295	2N1305
Q 403	TRANSISTOR 2N3414	8210-1290	56289	2N3414
Q 404	TRANSISTOR 2N1304	8210-1304	01295	2N1304
Q 405	TRANSISTOR 2N1304	8210-1304	01295	2N1304
Q 406	TRANSISTOR 2N3414	8210-1290	56289	2N3414
Q 407	TRANSISTOR 2N1304	8210-1304	01295	2N1304
Q 408	TRANSISTOR 2N1304	8210-1304	01295	2N1304
Q 409	TRANSISTOR 2N1305	8210-1305	01295	2N1305
R 409	RES COMP 180 K 5PCT 1/2W	6100-4185	81349	RCR20G184J
R 410	RES COMP 20 K OHM 5PCT 1/2W	6100-3205	81349	RCR20G203J
R 411	RES COMP 75 K OHM 5PCT 1/2W	6100-3755	81349	RCR20G753J
R 412	RES COMP 180 K 5PCT 1/2W	6100-4185	81349	RCR20G184J
R 413	RES COMP 150 K 5PCT 1/2W	6100-4155	81349	RCR20G154J
R 414	RES FLM 1.47K 1 PCT 1/4W	6350-1147	81349	RN60D1471F
R 415	RES FLM 741 OHM 1/2PCT 1/4W	6351-0741	81349	RN60D7410D
R 416	RES COMP 6.8 K 5PCT 1/2W	6100-2685	81349	RCR20G682J
R 417	RES COMP 330 OHM 5PCT 1/2W	6100-1335	81349	RCR20G331J
R 418	RES COMP 12 K 5PCT 1/2W	6100-3125	81349	RCR20G123J
R 419	RES COMP 30 K OHM 5PCT 1/2W	6100-3305	81349	RCR20G303J
R 420	RES COMP 150 K 5PCT 1/2W	6100-4155	81349	RCR20G154J
R 421	RES FLM 1.45K 1 PCT 1/4W	6350-1145	81349	RN60D1451F
R 422	RES FLM 759 OHM 1 PCT 1/4W	6350-0759	81349	RN60D7590F
R 423	RES COMP 6.8 K 5PCT 1/2W	6100-2685	81349	RCR20G682J
R 424	RES COMP 330 OHM 5PCT 1/2W	6100-1335	81349	RCR20G331J
R 425	RES COMP 12 K 5PCT 1/2W	6100-3125	81349	RCR20G123J
R 426	RES COMP 10 K 5PCT 1/2W	6100-3105	81349	RCR20G103J
R 427	RES COMP 100 OHM 5PCT 1/2W	6100-1105	81349	RCR20G101J
R 428	RES COMP 2.4 K OHM 5PCT 1/2W	6100-2245	81349	RCR20G242J
R 429	RES COMP 4.7 K 5PCT 1/2W	6100-2475	81349	RCR20G472J
R 431	RES COMP 220 OHM 5PCT 1/2W	6100-1225	81349	RCR20G221J
R 432	RES COMP 680 OHM 5PCT 1/2W	6100-1685	81349	RCR20G681J
R 475	RES COMP 10 K 5PCT 1/2W	6100-3105	81349	RCR20G103J
R 476	RES COMP 10 K 5PCT 1/2W	6100-3105	81349	RCR20G103J

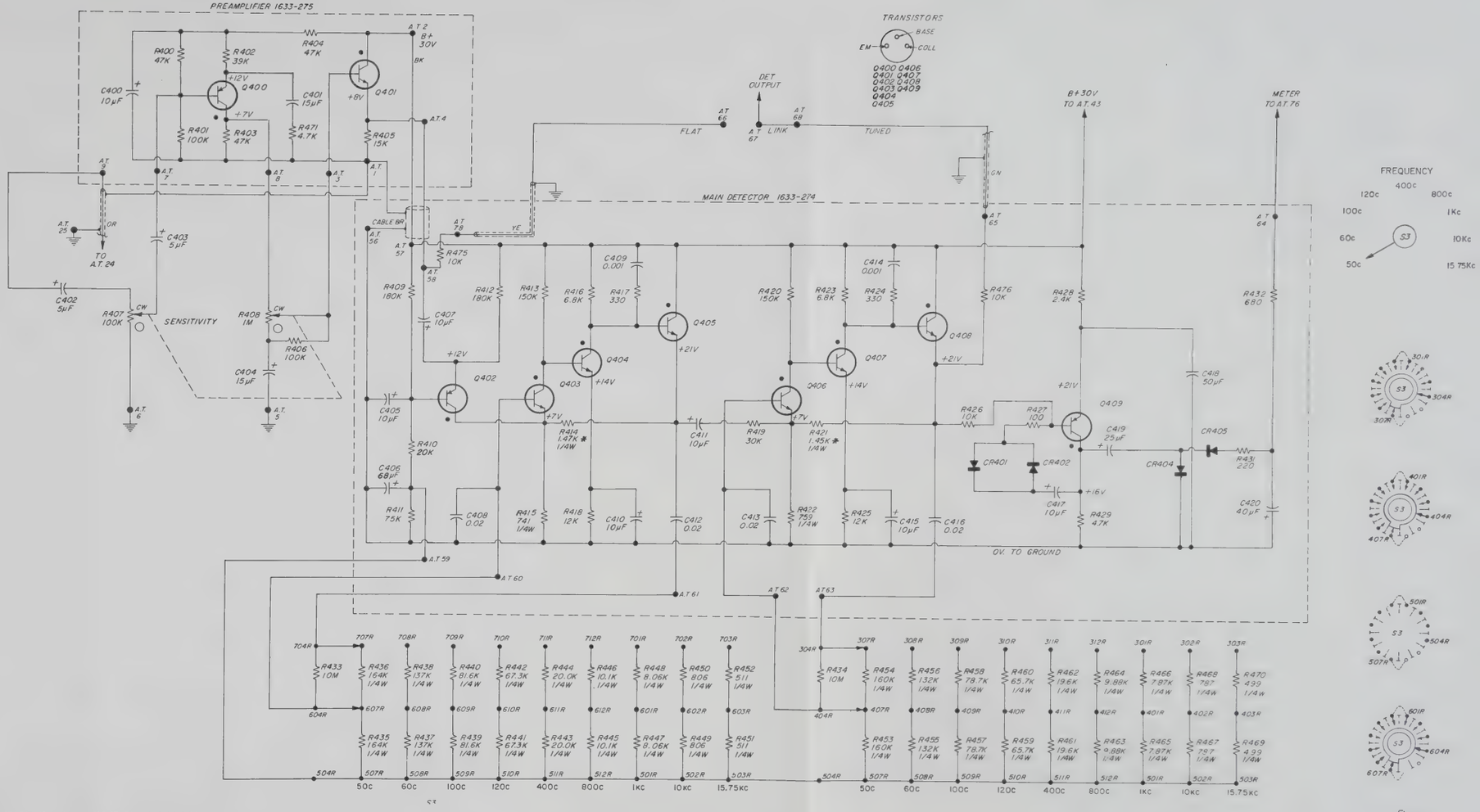
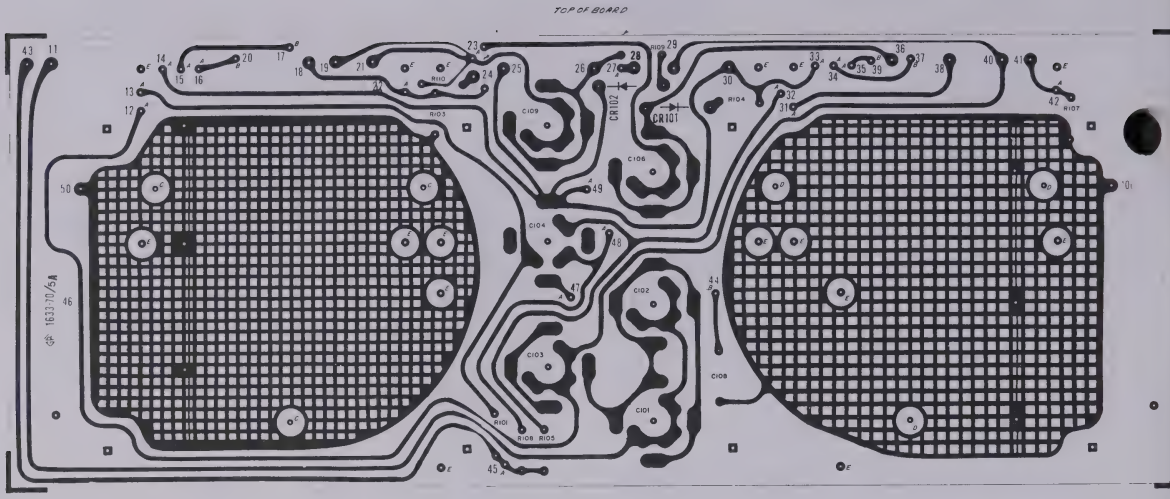
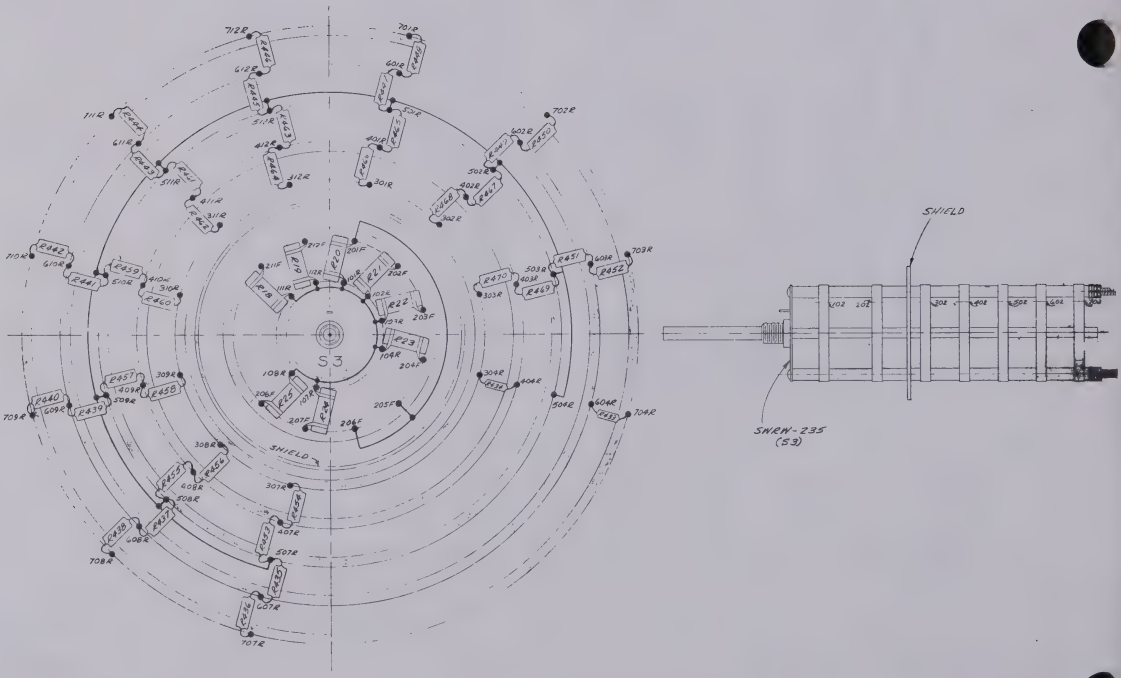


Figure 7-9. Schematic diagram of preamplifier and main detector.



Etched board layout for bridge circuitry



Wiring details for S3.

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually, the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

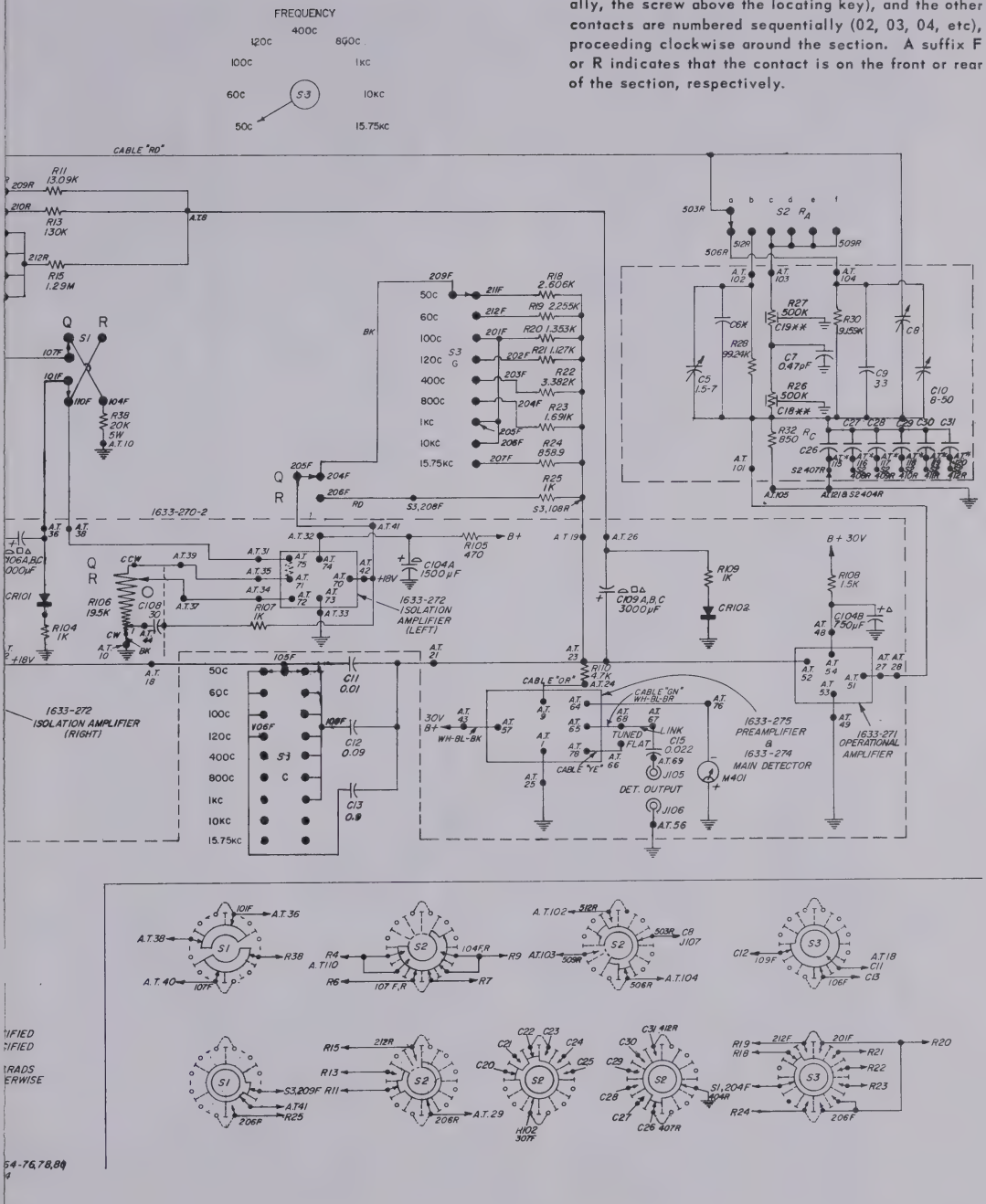


Figure 7-13. Schematic diagram of Type 1633-A Incremental Inductance Bridge.

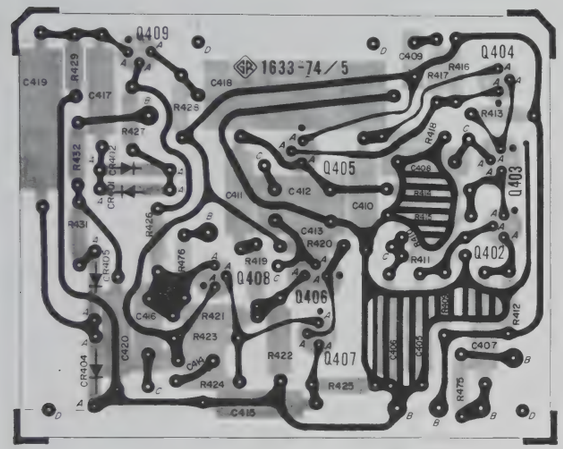


Figure 7-10. Etched board layout of main detector.

NOTE: The number on the foil side is not the part number for the complete assembly. The dot on the foil at the transistor socket indicates the collector lead.

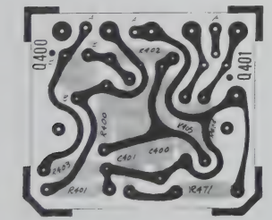


Figure 7-11. Etched board layout of preamplifier.

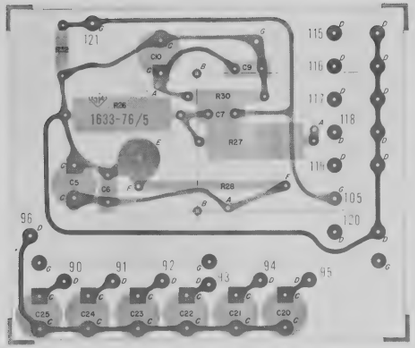
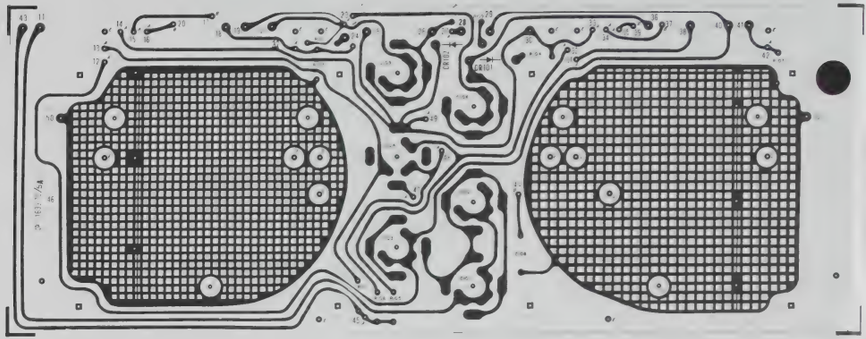
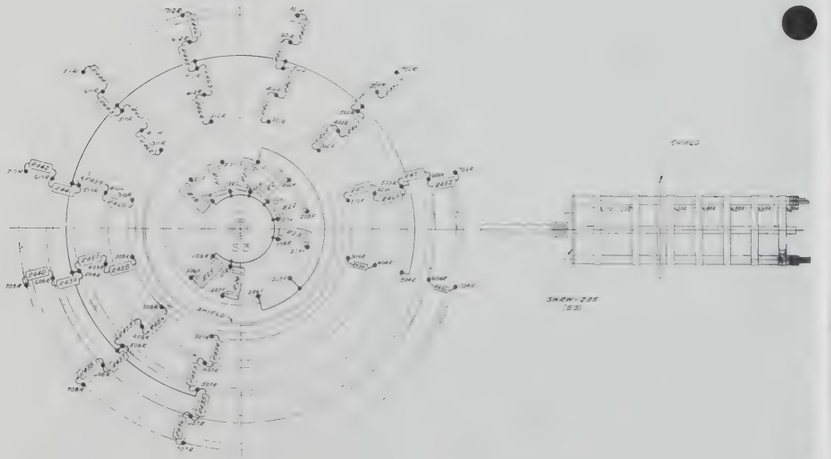


Figure 7-12. Switch-mounting etched board layout.



Etched board layout for bridge circuitry



Wiring details for S3.

ELECTRICAL PARTS LIST

BRIDGE CIRCUIT PC BOARD P/N 1633-2702

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 101	CAP ALUM 90-30-30 UF 300V	4450-3400	56289	60D 300V
C 102	CAP ALUM 90-30-30 UF 300V	4450-3400	56289	60D 300V
C 103	CAP ALUM 1500-750-750 UF 25V	4450-0700	56289	60D 25V
C 104	CAP ALUM 1500-750-750 UF 25V	4450-0700	56289	60D 25V
C 106	CAP ALUM 1500-750-750 UF 25V	4450-0700	56289	60D 25V
C 108	CAP MICA 30PF 10PCT 500V	4620-0650	81349	CM15D300K
C 109	CAP ALUM 1500-750-750 UF 25V	4450-0700	56289	60D 25V
CR 101	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
CR 102	DIODE RECTIFIER 1N4003	6081-1001	14433	1N4003
R 101	RES COMP 470 OHM 5PCT 1/2W	6100-1475	81349	RCR20G471J
R 102	POTENTIOMETER	0433-4090	24655	0433-4090
R 103	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 104	RES COMP 1.0 K .5PCT 1/2W	6100-2105	81349	RCR20G102J
R 105	RES COMP 470 OHM 5PCT 1/2W	6100-1475	81349	RCR20G471J
R 106	POTENTIOMETER	0433-4100	24655	0433-4100
R 107	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 108	RES COMP 1.5 K 5PCT 1/2W	6100-2155	81349	RCR20G152J
R 109	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J
R 110	RES COMP 4.7 K 5PCT 1/2W	6100-2475	81349	RCR20G472J

SWITCH MOUNTING PC BOARD P/N 1633-2760

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 5	CAP CER TRIM 1.5-7 PF	4910-1110	72982	557-051 A 1.5-7PF
C 6	FACTORY SELECT	****-****		
C 7	CAP CER TUB .47 PF 10PCT 500V	4400-1200	95121	QC 0.47PF 10PCT 500
C 8	TRIMMER BASE	1117-6020	24655	1117-6020
C 9	CAP MICA 33 PF 5PCT 500V	4700-0301	81349	CM05ED330JN
C 10	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 20	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 21	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 22	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 23	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 24	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 25	CAP CER TRIM 8-50 PF	4910-1170	72982	557-051 E 8-50PF
C 26	FACTORY SELECT	****-****		
C 27	FACTORY SELECT	****-****		
C 28	FACTORY SELECT	****-****		
C 29	FACTORY SELECT	****-****		
C 30	FACTORY SELECT	****-****		
C 31	FACTORY SELECT	****-****		
R 26	RES FLM 500K 1/25 PCT 50PPM 1W	6194-3500	81349	RN75C5003C
R 27	RES FLM 500K 1/25 PCT 50PPM 1W	6194-3500	81349	RN75C5003C
R 28	RES GR 99.24K OHM .2 PCT 1W	6983-5030	24655	6983-5030
R 30	RES GR 9.159K 0.25PCT 1/2W	6982-4000	24655	6982-4000
R 32	RES GR 85C OHM .25 PCT 1/8W	6981-3015	24655	6981-3015

PREAMPLIFIER PC BOARD P/N 1633-2750

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
C 400	CAP ALUM 10 UF 25V	4450-3800	56289	30D106G025
C 401	CAP ALUM 15 UF 15V	4450-3700	56289	30D156G015
Q 401	TRANSISTOR 2N3414	8210-1047	03508	2N3414
R 400	RES COMP 47 K 5PCT 1/2W	6100-3475	81349	RCR20G473J
R 401	RES COMP 100 K 5PCT 1/2W	6100-4105	81349	RCR20G104J
R 402	RES COMP 39 K 5PCT 1/2W	6100-3395	81349	RCR20G393J
R 403	RES COMP 47 K 5PCT 1/2W	6100-3475	81349	RCR20G473J
R 404	RES COMP 47 K 5PCT 1/2W	6100-3475	81349	RCR20G473J
R 405	RES COMP 15 K 5PCT 1/2W	6100-3155	81349	RCR20G153J
R 471	RES COMP 4.7 K 5PCT 1/2W	6100-2475	81349	RCR20G472J

Rotary switch sections are shown as viewed from the panel end of the shaft. The first digit of the contact number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually, the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

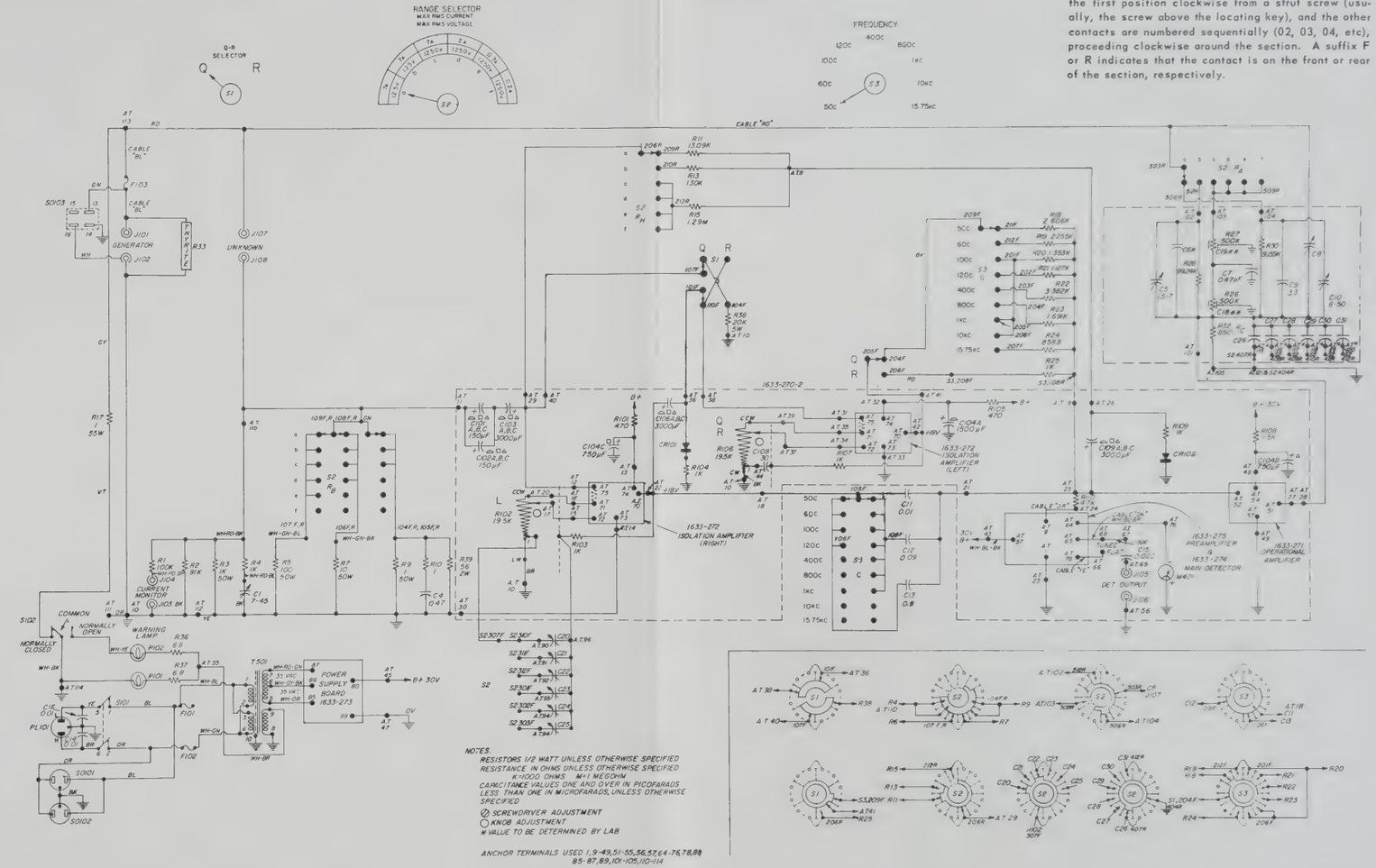


Figure 7-13. Schematic diagram of Type 1633-A Incremental Inductance Bridge.

ELECTRICAL PARTS LIST (cont)

CHASSIS MOUNTED PARTS P/N 1633-3100

REFDES	DESCRIPTION	PART NO.	FMC	MFGR PART NUMBER
R 444	RES FLM 20K 1 PCT 1/4W	6350-2200	81349	RN60D2002F
R 445	RES FLM 10.1K 1 PCT 1/4W	6350-2101	81349	RN60D1012F
R 446	RES FLM 10.1K 1 PCT 1/4W	6350-2101	81349	RN60D1012F
R 447	RES FLM 8.06K 1 PCT 1/4W	6350-1806	81349	RN60D8061F
R 448	RES FLM 8.06K 1 PCT 1/4W	6350-1806	81349	RN60D8061F
R 449	RES FLM 806 OHM 1 PCT 1/4W	6350-0806	81349	RN60D8060F
R 450	RES FLM 806 OHM 1 PCT 1/4W	6350-0806	81349	RN60D8060F
R 451	RES FLM 511 OHM 1 PCT 1/4W	6350-0511	81349	RN60D5110F
R 452	RES FLM 511 OHM 1 PCT 1/4W	6350-0511	81349	RN60D5110F
R 453	RES FLM 160K 1 PCT 1/4W	6350-3160	81349	RN60D1603F
R 454	RES FLM 160K 1 PCT 1/4W	6350-3160	81349	RN60D1603F
R 455	RES FLM 132K 1 PCT 1/4W	6350-3132	81349	RN60D1323F
R 456	RES FLM 132K 1 PCT 1/4W	6350-3132	81349	RN60D1323F
R 457	RES FLM 78.7K 1 PCT 1/4W	6350-2787	81349	RN60D7872F
R 458	RES FLM 78.7K 1 PCT 1/4W	6350-2787	81349	RN60D7872F
R 459	RES FLM 65.7K 1/2PCT 1/4W	6351-2657	81349	RN60D6572D
R 460	RES FLM 65.7K 1/2PCT 1/4W	6351-2657	81349	RN60D6572D
R 461	RES FLM 19.6K 1 PCT 1/4W	6350-2196	81349	RN60D1962F
R 462	RES FLM 19.6K 1 PCT 1/4W	6350-2196	81349	RN60D1962F
R 463	RES FLM 9.88K 1 PCT 1/4W	6350-1988	81349	RN60D9881F
R 464	RES FLM 9.88K 1 PCT 1/4W	6350-1988	81349	RN60D9881F
R 465	RES FLM 7.87K 1 PCT 1/4W	6350-1787	81349	RN60D7871F
R 466	RES FLM 7.87K 1 PCT 1/4W	6350-1787	81349	RN60D7871F
R 467	RES FLM 787 OHM 1 PCT 1/4W	6350-0787	81349	RN60D7870F
R 468	RES FLM 787 OHM 1 PCT 1/4W	6350-0787	81349	RN60D7870F
R 469	RES FLM 499 OHM 1 PCT 1/4W	6350-0499	81349	RN60D4990F
R 470	RES FLM 499 OHM 1 PCT 1/4W	6350-0499	81349	RN60D4990F
S 1	SWITCH ROTARY ASM	7890-2330	24655	7890-2330
S 2	SWITCH ROTARY ASM	7890-5333	24655	7890-5333
S 3	SWITCH ROTARY ASM	7890-2350	24655	7890-2350
S 101	SWITCH TOGGLE 2POS DPST STEADY	7910-0780	04009	81024-GB
S 102	SWITCH MICRO	1633-0420	91929	BA-2RQ1-A2
SO 103	RECPT JONES 4 CONT FEMALE	4230-0700	13150	S-5404-SB
T 501	TRANSFORMER POWER	0745-4210	24655	0745-4210

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00192	Jones Mfg.,Chicago,IL 60181
00194	Watsco Elctrnx.,Los Angeles,CA 90018
00327	Welwyn Instrs.,Westlake,OH 44145
00434	Schweitzer Electrnx.,Westbury,NY 11590
00656	Aerovox,.New Bedford,MA 02745
00779	AMP Inc.,Harrisburg,PA 17105
01009	Alden Products,.Brockton,MA 02413
01121	Allen Bradley.,Milwaukee,WI 53204
01255	Litton Inds.,Beverly Hills,CA 90213
01281	TRW,.Leaminade,CA 90260
01295	TI,.Dallas,TX 75222
01526	GE,.Waynesboro,VA 22980
01930	Amerock,.Rockford,IL 61101
01963	Cherry Electrx.,Waukegan,IL 60085
02111	Spectrol Electrx.,City of Industry,CA 91745
02114	Ferrocube,.Saugerties,NY 12477
02606	Fenwal Lab.,Morton Grove,IL 60053
02639	GE,.Schenectady,NY 12327
02660	Amphenol,.Broadview,IL 60153
02735	RCA,.Somerville,NJ 08876
02768	Fastex,.Desplaines,IL 60018
02842	Carter Ink.,Cambridge,MA 02142
03508	GE,.Syracuse,NY 13201
03550	Viangard Electrnx.,Inglewood,CA 90302
03636	Greybarne.,Yonkers,NY 10701
03877	Transistron Electrx.,Wakefield,MA 01880
03888	KDI Pyrofilm.,Whippany,NJ 07981
03911	Clarostat,.New York,NY 10901
04008	Arrow Hart.,Hartford,CT 06106
04041	Digitronics.,Albertson,NY 11507
04713	Motorola,.Phoenix,AZ 85008
04810	Components Mfg.,N.Bridgewater,MA 02379
05079	Tansistor Electrx.,Bennington,VT 05201
05245	Corcom,.Chicago,IL 60639
05276	ITT Electrx.,Pomona,CA 91766
05402	Controls Co.of Amer.,Melrose Pk,IL 60160
05624	Viking Inds.,Chatsworth,CA 91311
05624	Barber Colman.,Rockford,IL 61101
05745	Barnes Mfg.,Mansfield,OH 44901
05820	Wakefield Eng.,Wakefield,MA 01880
06383	Panduit.,Tinley Pk,IL 60477
06406	Truelove & Maclean.,Waterbury,CT 06708
06665	Precision Monolith.,Santa Clara,CA 95050
06743	Clevite,.Cleveland,OH 44110
06785	WL5 Stamp.,Cleveland,OH 44104
06915	Richco Plstc.,Chicago,IL 60646
06918	Teledyne Kinis.,Solana Bch,CA 92075
06976	Aladdin Electrx.,Nashville,TN 37210
07063	Ross Milton.,Southampton,PA 18966
07126	Digitran.,Pasadena,CA 91105
07127	Eagle Signal.,Baraboo,WI 53913
07263	Fnch Graphlk.,City of Industry,CA 91744
07261	Avnet.,Culver City,CA 90230
07263	Fairchild.,Mountain View,CA 94040
07387	Birtcher.,N.Los Angeles,CA 90032
07566	Amer.Siamonid.,Arlington Hts,IL 60004
07689	Magnetic Core.,Newburgh,NY 12550
07910	Continental Dvc.,Hawthorne,CA 90250
07933	State Labs.,New York,NY 10003
07989	Borg Inst.,Delavan,WI 53115
08524	Deutsch Fastener.,Los Angeles,CA 90040
08556	Bell Electrx.,Chicago,IL 60632
08730	Vermeulne Prod.,Franklin Lakes,NJ 07417
09213	GE,.Buffalo,NY 14220
09353	C&K Components.,Watertown,MA 02172
09408	Stat-Tronics,.Georgetown,MA 01830
09823	Burgess Battery.,Freeport,IL 61032
09856	Fenwal Electrx.,Framingham,MA 01701
09922	Burndy.,Norwalk,CT 06852
10025	Glaseal Prod.,Linden,NJ 07036
10389	Chicago Switch.,Chicago,IL 60647
11236	CTS of Berne.,Berne,IN 46711
11599	Chandler Evans.,W.Hartford,CT 06101
11963	Nortronics.,Minneapolis,MN 55427
12040	National.,Santa Clara,CA 95051
12045	Electr Transistrs.,Flushing,NY 11354
12408	Teledyne.,Mountain View,CA 94043
12617	Hamlin.,Lake Mills,WI 53551
12697	RCA.,Woodbridge,NJ 01095
12697	Clarostat.,Dover,NH 03820
12856	Micromeralx.,City of Industry,CA 91744
12954	Dickson Electrx.,Scottsdale,AZ 85252
12969	Unitrode.,Watertown,MA 02172
12984	Electrocraft.,Hopkins,MN 55343
13103	Thermalloy.,Dallas,TX 75234
13148	Voguel Inst.,Richmond Hill,NY 11418
13150	Vermitron.,Laconia,NH 03246
13327	Solitron Devices.,Tappan,NY 10983
13715	Fairchild.,San Rafael,CA 94903
13919	Burr Brown.,Tucson,AZ 85706
14010	Amadex Inst.,Van Nuys,CA 91406
14195	Electr Controls.,Wilton,CT 06897
14196	American Labs.,Fullerton,CA 92634
14332	Relton.,Arcadia,CA 91006
14433	ITT.,W.Palm Beach,FL 33402
14482	Watkins & Johnson.,Palo Alto,CA 94304
14698	Corbin.,Berlin,CT 06037
14655	Cornell Dubilier.,Newark,NJ 07101
14674	Corning Glass.,Corning,NY 14830
14749	Avopian.,Euston,PA 18042
14752	Electrocube.,San Gabriel,CA 91776
14889	R&G Sloan.,Sun Valley,CA 91352
14936	Electr Inst & Spclty.,Stoneham,MA 02180
14936	General Inst.,Hackettville,NY 11802
15238	ITT.,Lawrence,MA 08142
15476	Digital Equip.,Maynard,MA 01754

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Code	Manufacturer
15605	Cutler Hammer.,Milwaukee,WI 53202
15782	Houston Inst.,Bellaire,TX 77401
15801	Fenwal Electrx.,Framingham,MA 01701
15818	Sinclair & Rush.,St.Louis,MO 63111
16037	Spruce Pine Mica.,Spruce Pine,NC 28777
16068	Intrnl Diode.,Jersey City,NJ 07304
16179	Omni Spectra.,Farmington,MI 48024
16301	Astrolab.,Linden,NJ 07036
16352	Codi.,Fairlawn,NJ 07410
16485	Sterling Inst.,New Hyde Park,NY 11040
16636	Indiana General.,Oglesby,IL 61348
16758	Delco.,Kokomo,IN 46901
16950	Precision Dynamics.,Burbank,CA 91504
16952	Amer Micro Devices.,Summerville,SC 29483
17117	Electr Molding.,Woonsocket,RI 02895
17545	Michael-Spring.,Shiller Park,IL 60176
17745	Angstrohm Precsn.,Hagerstown,MD 21740
17871	Singer.,Somerville,NJ 08876
17850	Zeltex.,Concord,CA 94520
17856	Siliconix.,Santa Clara,CA 95054
18324	Signetics.,Sunnyvale,CA 94086
18542	New Prod Eng.,Wabash,IN 46992
18612	Carter Ink.,Cambridge,MA 02142
18736	Computer Diode.,S.Fairlawn,NJ 07936
18795	Exicon.,Sunnyvale,CA 94086
19207	Durant.,Watertown,WI 53094
19209	GE,.Gainesville,FL 32601
19315	Eastron.,Haverhill,MA 01830
19396	Paktron.,Vienna,VA 22180
19647	Calmos.,Chicago,IL 60622
19644	LRC Electrx.,Horsheads,NY 14845
19701	Electra.,Independence,KS 67301
20093	Elect Inds.,Murray Hill,NJ 07974
20354	KMC.,Long Valley,NJ 07853
21525	Filtron Bearing.,New Britain,CT 06050
21688	Raytheon.,Norwood,MA 02062
21759	Lenox Fugle.,Watchung,NJ 07060
22526	Berg Electrx.,New Cumberland,PA 17070
22753	Electro Space Fabrctn.,Tupson,PA 19562
22753	UID Electrx.,Hollywood,FL 33022
23338	Westek.,San Diego,CA 92112
23342	Avnet Electrx.,Franklin Park,IL 60131
23450	Pulsetor.,Burlington,CA 94010
24355	Indiana Gnrl Electrx.,Keasby,NJ 08832
24355	Analog Devices.,Cambridge,MA 02142
24444	General Semicond.,Tempe,AZ 85281
24446	GE,.Schenectady,NY 12305
24482	GE,.Syracuse,NY 13201
24655	GE,.Cleveland,OH 44112
24602	EMC Technlgy.,Cherry Hill,NJ 08034
24655	Gen Rad.,Concord,MA 01742
24759	Electra Fugle.,S.Plainfield,NJ 07080
25008	Vactite.,Berkeley,CA 94710
25289	EG&G.,Bedford,MA 01730
26601	Tri-County Tube.,Nunda,NY 14517
26805	Omni Spectra.,Waltham,MA 02154
26806	American Zettler.,Costa Mesa,CA 92626
27014	National.,Santa Clara,CA 95051
27545	Hartford Universal Ball.,Rocky Hill,CT 06067
28480	HP.,Palo Alto,CA 94304
28520	Heyman Mfg.,Kenilworth,NJ 07033
28875	IMC Magnetics.,Rochester,NH 03867
28959	Hoffman Electrx.,El Monte,CA 91734
30043	Solid State Devices.,LaMirada,CA 90638
30646	Beckman Inst.,Cedar Grove,NJ 07009
30874	IBM.,Armonk,NY 10504
30985	Pennsy Magnetics.,Toledo,OH 43609
31019	Solid State Scntfc.,Monigomerville,PA 18936
31514	Stanford Applid Engs.,Costa Mesa,CA 92626
31814	Analogic.,Wakefield,MA 01880
31951	Trindge.,Pittsburgh,PA 15231
32001	Jensen.,Chicago,IL 60638
32293	Spectrum Control.,Fairview,PA 16415
33173	GE,.Owensboro,KY 42301
34141	Koehler.,Marlboro,MA 01752
34156	Semicos.,Costa Mesa,CA 92626
34333	Silicon Genl.,Westminster,CA 92683
34335	Advanced Micro Devices.,Sunnyvale,CA 94086
34649	Intrsl.,Santa Clara,CA 95051
34677	Solitron Devices.,Jupiter,FL 33458
35609	Constantia.,Montreal,QUE,CAN
36462	National Ltd.,Montreal,QUE,CAN
37942	Mallory.,Indianapolis,IN 46206
38443	Martin Rockwell.,Jamestown,NY 14701
38477	McGill Mfg.,Valparaiso,IN 46383
40931	Penray.,Minneapolis,MN 55408
42190	Muter.,Chicago,IL 60638
42496	National.,Melrose,MA 02176
43334	New Departure-Hyatt.,Sandusky,OH 44870
43991	Norma Hoffman.,Stamford,CT 06904
49671	RCA.,New York,NY 10020
49956	Raytheon.,Waltham,MA 02154
50088	Mostek.,Carrollton,TX 75006
50101	Girtz Devices.,S.Chelmsford,MA 01824
50507	Micro Networks.,Worcester,MA 01606
50662	Monsanto.,Palo Alto,CA 94304
50721	Datel Systems.,Canton,MA 02021
51167	Arnel Electrx.,Frenchtown,NJ 08825
51563	Diablo Systems.,Hayward,CA 94545
51642	Centre Eng.,State College,PA 16801
52648	Preser.,Santa Ana,CA 92705
52676	SKF Inds.,Philadelphia,PA 19132
52763	Sterner Truth.,Caernovia,NY 13035
53021	Sangamo Electrx.,Springfield,IL 62705
53184	Xcelon.,Lanham,MY 12510
53421	Tyrton.,Milwaukee,WI 53209
54294	Shallrose.,Selma,NC 27576
54297	Assoc Prod.,Hunterville,AL 35805
54715	Shure Bros.,Evanston,IL 60202

Code	Manufacturer
55285	Spraque.,North Adams,MA 01247
55771	Shimpson.,Bayport,NY 11705
58053	Superior Valve.,Washington,PA 15301
58730	Thomas & Betts.,Elizabeth,NJ 07201
59875	TRW.,Cleveland,OH 44117
60299	Torrington.,Torrington,CT 06790
61007	Townsend.,Braintree,MA 02184
61637	Union Carbide.,New York,NY 10017
61864	United Carr Fast.,Boston,MA
62060	Victoreen.,Cleveland,OH 44104
63743	Ward Leonard.,Mt.Vernon,NY 10550
65093	Weldon.,Bloomfield,NJ 07003
65092	Weston.,Newark,NJ 07114
70106	Wurlitzer Cap.,New Bedford,MA 02742
70109	Adams & Westlake.,Elkhart,IN 46514
70417	Chrysler.,Detroit,MI 48231
70485	Atlantic India Rubber.,Chicago,IL 60607
70903	Beldon.,Chicago,IL 60644
71126	Bronson.,Beacon Falls,CT 06403
71279	Cambridge Thermonic.,Cambridge,MA 02138
71294	Canfield.,Clifton Forge,VA 24422
71400	Bussmann.,St.Louis,MO 63107
71450	CTS.,Elkhart,IN 46514
71468	Cannon.,Los Angeles,CA 90031
71482	Clare.,Chicago,IL 60645
71590	Centralab.,Milwaukee,WI 53212
71666	Continental Carbon.,New York,NY
71707	Coto Coil.,Providence,RI 02905
71729	Crescent Box.,Philadelphia,PA 19134
71744	Chicago Min Lamp.,Chicago,IL 60640
71785	Cinch.,Chicago,IL 60624
71823	Darnell.,Downey,CA 90241
72136	Electromotive.,Williamsville,CT 06226
72228	Continental Screw.,New Bedford,MA 02742
72259	Wyrosics.,Berkeley Hts,NJ 07922
72619	Dialight.,Brooklyn,NY 11237
72699	General Inst.,Newark,NJ 07104
72765	Drake.,Chicago,IL 60631
72794	Dzus Fastener.,W.Islip,NY 11795
72825	Eby.,Philadelphia,PA 19144
72962	Elastic Stop Nut.,Union,NJ 07083
72982	Ero.,Erie,PA 16512
73445	Amperex Electrx.,Hicksville,NY 11801
73559	Carling Electrx.,Hartford,CT 06110
73724	Erie Resistor.,New York,NY
73803	TI.,Attleboro,MA 02703
73899	JFD Electrx.,Brooklyn,NY 11219
73957	Groov-Pin.,Ridgefield,NJ 07657
74193	Heyman.,Trenton,NJ 08602
74199	Quam Nichols.,Chicago,IL 60637
74445	Hoto-Krome.,Hartford,CT 06110
74545	Hubbel.,Stratford,CT 06497
74868	Industrial Cndnsr.,Chicago,IL 60618
74970	Johnson.,Waseca,MN 56093
75042	INTTRWI.,Burlington,IA 52601
75376	Kurz-Kasch.,Dayton,OH 45401
75382	Kulka.,Mt.Vernon,NY 10551
75491	Lafayette.,Syosset,NY 11791
75605	Lincoln.,Providence,RI 02905
75915	Littelfuse.,Des Plains,IL 60016
76005	Lord Mfg.,Erie,PA 16512
76149	Mallory Electrx.,Detroit,MI 48204
76241	Maxwell.,Chicago,IL 60616
76381	3 M Co.,St.Paul,MN 55101
76385	Minor Rubber.,Bloomfield,NJ 07003
76487	Millen.,Malden,MA 02148
76545	Mueller Elctr.,Cleveland,OH 44114
76568	National Tube.,Pittsburg,PA
76854	Oak Inds.,Crystal Lake,IL 60014
77122	Oak Fastener.,Waterbury,CT 06720
77147	Patton MacGuyer.,Providence,RI 02905
77168	Pas Sevenson.,Syracuse,NY 13209
77263	Pierce Roberts Rubber.,Trenton,NJ 08638
77315	Pluti Bros.,Waterbury,CT 06720
77339	Positive Lockwasher.,Newark,NJ
77342	AMP.,Princeton,IN 47570
77542	Ray-o-Vac.,Madison,WI 53703
77630	TRW.,Camden,NJ 08103
77638	General Inst.,Brooklyn,NY 11211
78189	Illinois Tool.,Elgin,IL 60120
78277	Sigma Inst.,Braintree,MA 02184
78429	Axico Steer.,St Marys,PA 15857
78488	Stackpole.,St Marys,PA 15857
78553	Timberman.,Cleveland,OH
78711	Telephonics.,Huntington,NY 11743
79069	RCA.,Harrison,NJ 07029
79136	Waldes Kohinoor.,New York,NY 11101
79497	Western Rubber.,Goshen,IN 46526
79725	Wrnmold.,Hartford,CT 06110
79727	Continental Wirr.,Philadelphia,PA 19101
79840	Mallory Cmnds.,Franklin,IN 46041
79963	Zierick.,Mt Kisco,NY 10549
80009	Tektronix.,Beaverton,OR 97005
80030	Prestole Fastener.,Toledo,OH 43605
80048	Vickers,St Louis,MO 63166
80103	Lambda.,Melville,NY 11746
80183	Sprague.,N.Adams,MA 01247
80211	Motorola.,Franklin Pk,IL 60131
80251	Formica.,Cincinnati,OH 45232
80258	Standard Oil.,Lafayette,IN 47902
80294	Bourns Labs.,Riverside,CA 92506
80366	Sylvania.,New York,NY 10017
80431	Air Filter.,Milwaukee,WI 53218
80583	Hammarlund.,New York,NY 10010
80740	Beckman Inst.,Fullerton,CA 92634
80756	TRW Ramsey.,St Louis,MO 63166

Code	Manufacturer
80894	Pure Carbon.,St Marys,PA 15857
81030	Int'l Inst.,Orange,CT 06477
81073	Grayhill.,LaGrange,IL 60525
81143	Isolantite.,Stirling,NJ 07980
81312	Winchester.,Oakville,CT 06779
81348	Military Specifications
	Joint Army-Navy Specifications
81483	Int'l Rectifier.,El Segundo,CA 90245
81741	Chicago Lock.,Chicago,IL 60641
81831	Filtron.,Flushing,NY 11354
81840	Ledex.,Dayton,OH 45402
81860	Barry Wright.,Watertown,MA 02172
82219	Sylvania.,Emporium,PA 15834
82227	No.Amer Philips.,Cheshire,CT 06410
82273	IN Pattern & Model.,LaPorte,IN 46350
82389	Switchcraft.,Chicago,IL 60630
82567	Reeves Hoffman.,Carlisle,PA 17013
82647	Metals & Controls.,Attleboro,MA 02703
82807	Milwaukee Resistor.,Milwaukee,WI 53204
82877	Rosnon.,Woodstock,NY 12498
82901	IN General Magnet.,Valparaiso,IN 46383
83003	Varo.,Garland,TX 75040
83014	Hanwell.,Pleasantville,NJ 08232
83033	Meissner.,Mt Carmel,IL 62863
83058	Carr Fastener.,Cambridge,MA 02142
83186	Victory Eng.,Springfield,NJ 07081
83259	Parker Seal.,Culver City,CA 90231
83330	H.H.Smith.,Brooklyn,NY 11207
83361	Bearing Spclty.,San Francisco,CA
83587	Solar Electr.,Warren,PA 16365
83594	Burroughs.,Plainfield,NJ 07061
83740	Union Carbide.,New York,NY 10017
83766	Mass Engrs.,Quincy,MA 02171
83781	National Electrx.,Geneva,IL 60134
84411	TRW.,Ogallala,NB 69153
84835	Lehigh Metals.,Cambridge,MA 02140
84970	Sorbo Tarzian.,Bloomington,IN 47401
84971	TA Mfg.,Los Angeles,CA 90039
85604	Kepco.,Flushing,NY 11352
85620	Piston Casters.,Gurnee,IL 60031
86577	Prec Metal Prod.,Stoneham,MA 02180
86684	RCA.,Harrison,NJ 07029
86687	REC.,New Rochelle,NY 10801
86800	Conn Electrx.,Brooklyn,NY 11222
88140	Cutler Hammer.,Lincoln,IL 62656
88204	GTE Sylvania.,Ipswitch,MA 01938
88219	Gould Nat Battery.,Trenton,NJ 08607
88419	Cornell Dubilier.,Fuquay Varina,NC 27526
88927	K&G Mfr.,New York,NY
89265	Poirier & Brumfield.,Princeton,IN 47671
89482	Holtzer Cabot.,Boston,MA 02119
89665	United Transformer.,Chicago,IL
89870	Berkshire Transformer.,Kent,CT 06757
90201	Mallory Cap.,Indianapolis,IN 46206
90303	Mallory Bat.,Tarrytown,NY 10591
90634	Gulton Inds.,Metuchen,NJ 08840
90750	Westinghouse,Boston,MA 02118
90952	Hardware Prod.,Reading,PA 19602
91032	Continental Wire.,York,PA 17405
91146	Cannon.,Salem,MA 01970
91210	Gerber.,Mishawaka,IN 46544
91293	Johanson.,Boonton,NJ 07005
91417	Harris.,Melbourne,FL 32901
91506	August Bros.,Attleboro,MA 02703
91598	Chandler.,Wethersfield,CT 06109
91637	Dale Electrx.,Columbus,NE 68601
91662	Elco.,Willow Grove,PA 19090
91719	General Inst.,Dallas,TX 75220
91836	Kings Electrx.,Tuckahoe,NY 11223
91919	Mephisto Tool.,Hudson,NY 12534
91929	Honeywell.,Freeport,IL 61032
92519	Electra Insul.,Woodside,NY 11377
92678	Edgerton Germeshausen.,Boston,MA 02115
92702	IMC Magnetics.,Westbury,NY 11591
92739	Ampex.,Redwood City,CA 94063
92966	Hudson Lamp.,Kearny,NJ 07032
93332	Sylvania.,Woburn,MA 01801
93346	Amer Electrx Labs.,Lansdale,PA 19446
93618	R&C Mfg.,Ramsey,PA 16671
93916	Cramer.,New York,NY 10013
94144	Raytheon.,Quincy,MA 02169
94154	Wagner Electr.,Livingston,NJ 07039
94271	Weston.,Archibald,PA 18403
94322	Tel Labs.,Menlo Park,CA 94025
94589	Dickson.,Chicago,IL 60619
94688	Magnecraft.,Chicago,IL 60630
94800	Atlas Ind.,Brooklyne,NH 03033
95076	Garde.,Cumberland,RI 02864
95121	Quality Comp.,St Marys,PA 15857
95146	Alco Electrx.,Lawrence,MA 01843
95220	Continental Conn.,Woodside,NY 11377
95275	Vitramon.,Bridgeport,CT 06601
95348	Gordos.,Bloomfield,NJ 07003
95354	Methode.,Rolling Meadow,IL 60008
95704	Amp Brs.,Torrance,CA 90509
95987	Weckesser.,Chicago,IL 60646
96095	Aerovox Hi Q.,Olean,NY 14760
96341	Microwave Assoc.,Burlington,MA 01801
96906	Military Standards
97918	Linemaster Switch.,Woodstock,CT 06281
98291	Sealectro.,Mamaroneck,NY 10544
98474	Compar.,Burlingame,CA 94010
98821	North Hills.,Glen Cove,NY 11542
99017	Protective Closures.,Buffalo,NY 14207
99117	Mepsrec.,Flushing,NY 11358
99213	Varian.,Palo Alto,CA 94303
99378	Atlee.,Winchester,MA 01890
99800	Delevan,E Aurora,NY 14052
99934	Renbrandt.,Boston,MA 02118
99942	Centralab.,Milwaukee,WI 53201

ELECTRICAL PARTS LIST

CHASSIS MOUNTED PARTS P/N 1633-3100

REFDES	DESCRIPTION	PART NO.	FMC	MFGR	PART NUMBER
C 1	CAP CER TRIM 7-45 PF	4910-0100	24655	4910-0100	
C 4	CAP MYLAR .47UF 10 PCT 100V	4860-8248	56289	410P 0.47 UF 10PCT	
C 11	CAPACITOR .01 UF	0505-4412	24655	0505-4412	
C 12	CAP POLY .09UF 0.25PCT 50V	4872-1199	24655	4872-1199	
C 13	CAP POLY 0.9UF 0.25PCT 100V	4872-1041	24655	4872-1041	
C 14	CAP CER DISC.01UF 80/20PCT 500V	4406-3109	72982	0811082Z5U00103Z	
C 15	CAP CER DISC.022UF80/20PCT 500V	4407-3229	72982	0841087Z5U00223Z	
C 16	CAP CER DISC.01UF 80/20PCT 500V	4406-3109	72982	0811082Z5U00103Z	
C 402	CAP ALUM 5 UF 50V	4450-3900	56289	30D156G050	
C 403	CAP ALUM 5 UF 50V	4450-3900	56289	30D156G050	
C 404	CAP ALUM 15 UF 15V	4450-3700	56289	30D156G015	
F 101	FUSE SLO-BLOW 1/10A 250V	5330-0400	75915	313 .100	
F 102	FUSE SLC-BLOW 1/10A 250V	5330-0400	75915	313 .100	
F 103	FUSE SLO-BLOW 10A 32V	5330-2600	75915	313 010	
J 101	BINDING PCST ASM	0938-3002	24655	0938-3002	
J 102	BINDING PCST ASM	0938-3002	24655	0938-3002	
J 103	BINDING PCST ASM	0938-3022	24655	0938-3022	
J 104	BINDING PCST ASM	0938-3032	24655	0938-3032	
J 105	BINDING PCST ASM	0938-3032	24655	0938-3032	
J 106	BINDING PCST ASM	0938-3032	24655	0938-3032	
J 107	BINDING PCST ASM	0938-3002	24655	0938-3002	
J 108	BINDING PCST ASM	0938-3002	24655	0938-3002	
M 401	METER	5730-1260	24655	5730-1260	
P 101	LAMP FLANGE BASE 6V 0.2A 1000H	5600-0300	71744	CM-328	
P 102	LAMP FLANGE BASE 6V 0.2A 1000H	5600-0300	71744	CM-328	
PL 101	CONNECTOR POWER PLUG	4240-0701	24655	4240-0701	
Q 301	TRANSISTOR 2N1305	8210-1305	01295	2N1305	
Q 400	TRANSISTOR 2N1305	8210-1305	01295	2N1305	
R 1	RES FLM 100K 1 PCT 1/2W	6450-3100	81349	RN65D1003F	
R 2	RES COMP 91 K OHM 5PCT 1/2W	6100-3915	81349	RCR20G913J	
R 3	RES PREC WW 1 K .25 PCT 50W	6730-5311	24655	6730-5311	
R 4	RES COMP 1.0 K 5PCT 1/2W	6100-2105	81349	RCR20G102J	
R 5	RES PREC WW 100 OHM .25 PCT 50W	6730-5211	24655	6730-5211	
R 7	RES PREC WW 10 OHM .25 PCT 50W	6730-5111	24655	6730-5111	
R 9	RES PREC WW 1 OHM .25 PCT 50W	6730-5011	24655	6730-5011	
R 10	RES WW MCLDED 1 OHM 10 PCT 2W	6760-9109	75042	BWH 1 OHM 10PCT	
R 11	RES GR 13.09K 0.25PCT 1/2W	6982-5005	24655	6982-5005	
R 13	RES FLM 130K 1 PCT 1/2W	6450-3130	81349	RN65D1303F	
R 15	RES FLM 1.29M 1 PCT 1/2W	6450-4129	81349	RN65D1294F	
R 17	RES WW 1 OHM 10 PCT 55W	6640-0019	24655	6640-0019	
R 18	RES GR 2.706K OHM .25 PCT 1/8W	6981-4030	24655	6981-4030	
R 19	RES GR 2.255K OHM .25 PCT 1/8W	6981-4016	24655	6981-4016	
R 20	RES GR 1.353K OHM .25 PCT 1/8W	6981-4013	24655	6981-4013	
R 21	RES GR 1.127K OHM .25 PCT 1/8W	6981-4012	24655	6981-4012	
R 22	RES GR 3.382K OHM .25 PCT 1/8W	6981-4022	24655	6981-4022	
R 23	RES GR 1.691K OHM .25 PCT 1/8W	6981-4015	24655	6981-4015	
R 24	RES GR 858.9 OHM .25 PCT 1/8W	6981-3016	24655	6981-3016	
R 25	RES GR 1K OHM .25 PCT 1/8W	6981-4010	24655	6981-4010	
R 33	RES MYR 2000	6740-1300	03508	T2R-2100	
R 36	RES WW MCLDED 6.8 OHM 10 PCT 2W	6760-9689	75042	BWH 6.8 OHM 10PCT	
R 37	RES WW MCLDED 6.8 OHM 10 PCT 2W	6760-9689	75042	BWH 6.8 OHM 10PCT	
R 38	RES WW AX LEAD 20K OHM 5 PCT 5W	6660-3205	75042	AS-5 20K 5PCT	
R 39	RES COMP 56 OHM 5PCT 2W	6120-0565	81349	RCR42G560J	
R 406	RES COMP 100 K 5PCT 1/2W	6100-4105	81349	RCR20G104J	
R 407	POTENTICMETER (GANG)	1633-0410	24655	1633-0410	
R 408	POTENTIOMETER (GANG)	1633-0410	24655	1633-0410	
R 433	RES COMP 10 M 5PCT 1/2W	6100-6105	81349	RCR20G106J	
R 434	RES COMP 10 M 5PCT 1/2W	6100-6105	81349	RCR20G106J	
R 435	RES FLM 164K 1 PCT 1/4W	6350-3164	81349	RN60D1643F	
R 436	RES FLM 164K 1 PCT 1/4W	6350-3164	81349	RN60D1643F	
R 437	RES FLM 137K 1 PCT 1/4W	6350-3137	81349	RN60D1373F	
R 438	RES FLM 137K 1 PCT 1/4W	6350-3137	81349	RN60D1373F	
R 439	RES FLM 81.6K 1 PCT 1/4W	6350-2816	81349	RN60D8162F	
R 440	RES FLM 81.6K 1 PCT 1/4W	6350-2816	81349	RN60D8162F	
R 441	RES FLM 67.3K 1/2PCT 1/4W	6351-2673	81349	RN60D6732D	
R 442	RES FLM 67.3K 1/2PCT 1/4W	6351-2673	81349	RN60D6732D	
R 443	RES FLM 20K 1 PCT 1/4W	6350-2200	81349	RN60D2002F	

ELECTRICAL PARTS LIST (cont)

CHASSIS MOUNTED PARTS P/N 1633-3100

REFDES	DESCRIPTION	PART NO.	FMC	MFGR	PART NUMBER
R 444	RES FLM 20K 1 PCT 1/4W	6350-2200	81349	RN60D2002F	
R 445	RES FLM 10.1K 1 PCT 1/4W	6350-2101	81349	RN60D1012F	
R 446	RES FLM 10.1K 1 PCT 1/4W	6350-2101	81349	RN60D1012F	
R 447	RES FLM 8.06K 1 PCT 1/4W	6350-1806	81349	RN60D8061F	
R 448	RES FLM 8.06K 1 PCT 1/4W	6350-1806	81349	RN60D8061F	
R 449	RES FLM 806 OHM 1 PCT 1/4W	6350-0806	81349	RN60D8060F	
R 450	RES FLM 806 OHM 1 PCT 1/4W	6350-0806	81349	RN60D8060F	
R 451	RES FLM 511 OHM 1 PC

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